Early Agricultural Communities in Northern and Eastern India: an archaeobotanical investigation.

Volume I

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PhD Thesis by Emma Louise Harvey

Abstract

This thesis aims to contribute to the growing knowledge of early agricultural communities in India. The transition to agriculture is a fundamental change in society however, less is known about this transformation in the Indian sub-continent than other world regions. In this thesis the focus is on the Northern and Eastern areas of India and specifically the Ganges Plain and the state of Orissa. Some archaeobotanical work has been conducted in the Gangetic area but this work lacks quantification making it hard to compare to better studied regions (South India and Northwestern India). A number of sites in the Belan River Valley are investigated here and these sites (Chopani-Mando, Koldihwa, and Mahagara) have been suggested to be only evidence of a transition from wild rice exploitation to domestic rice agriculture although no systematic archaeobotanical analysis had been conducted. A methodological study of rice identification methods has been conducted as part of this thesis to help to clarify this issue. This thesis found this transition was unlikely to take place because dating of these sites does not demonstrate a continuous chronology and the evidence for wild rice at Chopani-Mando is not present. Koldihwa and Mahagara do show evidence of rice cultivation as well as having introduced crops (wheat, barley, winter pulses, native India pulses and millets).

Orissa has had no previous archaeobotanical studies conducted and therefore this thesis is the first to present evidence for the early agricultural communities in this area. There seems to be a rather late appearance of agriculture in the Chalcolithic period found at sites in the coastal and lowland areas (Golbai Sasan and Gopalpur). Rice, native India pulses (horsegram, pigeonpea, and *Vigna* sp.), and millets have been found at these sites. No introduced winter crops were found. The Central and Northern uplands of Orissa do not demonstrate the same subsistence pattern. There was no evidence of agricultural or wild plant food found at the sites (Bajpur, Banabasa, Malakhoja) investigated in this thesis.

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Chapter 1

Introduction to project aims and objectives

1.1 Introduction

Questions of agricultural origins are common in archaeological literature but usually concentrate on the better known regions of the Near East, Tropical America, and the Far East. The transition to agriculture, whether through an indigenous domestication or the spread of an existing agricultural system, is a fundamental development to be investigated in archaeology. India is a very large landmass containing many different environments and therefore the development of economic systems is likely to include diverse agricultural practices such as rain-fed cultivation, shifting cultivation, and systems of irrigation. Addressing this complex issue is never straightforward and this is especially true of India where datasets are erratic in occurrence and quality. This lack of data has led to India being overlooked on the whole and only recently has there been a concerted effort to address this neglect.

Archaeobotanical work in India including systematic flotation is growing but has concentrated on the Northwest (Weber 1990, 1991, 1993, 1997, Reddy 1991, 1994, 1997, 2003, Meadows 1989, 1996, Weber & Belcher 2003) and South India (Fuller 1999, 2002a, 2003, Fuller et al. 2001) leaving major lacunae in our understanding of prehistoric plant subsistence in other parts of the subcontinent. There has been a fair amount of archaeobotanical work conducted in the Ganges reason as well but this work lacks serious data analysis and quantification making it hard to compare to other more recent work in other areas. The other regions of India are particularly devoid of archaeobotanical investigations, especially Eastern India where few prehistoric excavations have taken place let alone any with systematic environmental sampling. This lack of archaeobotanical work is surprising as the Gangetic region and Eastern India offers great potential for investigating indigenous domestications.

As far as phytolith analysis is concerned, little work has been conducted in the whole of South Asia (Fujiwara 1992, Kajale et al. 1995, Madella 1995, 1997, 2003, Kajale & Eksambekar 1997, 2001a, 2001b, Eksambekar et al. 1999, Harvey et al. 2005) and this presents certain problems for beginning investigations such as establishing a reference collection for the region. However, the persistence of phytoliths in tropical areas offers great potential to complement organic archaeobotanical assemblages and should be incorporated more frequently into archaeological projects in South Asia.

This project seeks to contribute to the growing body of archaeobotanical work in India concentrating specifically on Northern and Eastern prehistoric sites (see figure 1.1 for map of study areas). In North-Central India, the early farming sites located in the Belan River Valley (part of the Vindhyas culture) are reported to have the earliest evidence of rice domestication (Sharma et al. 1980b). However, there is controversy over the dating of these sites (Allchin & Allchin 1982: 118, Pandey 1988, Kajale 1991: 169, Possehl & Rissman 1992, Bellwood 1996: 488, Glover & Higham 1996: 416, Mandal 1997, Tewari et al. 2000, Singh 2001, Fuller 2002a: 299, Tewari et al. 2003) and the archaeobotanical evidence is currently poor due to a lack of systematic sampling and flotation, and also a lack of quantification. A re-examination of these sites, which includes hunter-gatherer sites and farming settlements, will elucidate whether this is in fact an area of indigenous domestication and establish a more detailed insight into the economic systems of these communities.

Orissa, in Eastern India, has been completely neglected as far as archaeobotanical work is concerned. Few excavations have taken place in this state (Sengupta & Panja 2002:

1) and therefore any such work will add a great deal to the archaeological knowledge of the area. This is an intriguing area to investigate because it has continuous hunter-gatherer groups until the present day, the potential for considerable indigenous domestications suggested by the potential wild progenitors for some native Indian crops such as rice, red gram, and root crops, as well as the possibility of introduced agricultural systems from the rest of the Indian subcontinent, East Asia and Southeast Asia.

1.2 Research aims and objectives

As stated above, the main focus of this thesis is to examine the development of agricultural communities in Northern and Eastern India by conducting an archaeobotanical investigation, using both macro-botanical remains and phytolith analysis, of a number of prehistoric sites. For each of these regions, we can ask whether the economic system developed independently from native wild species, or was it an introduced agricultural system spread from elsewhere. Therefore can a progression from wild to domestic rice be seen, as has been suggested for the sites in the Belan River Valley? What sort of agricultural systems were developed and how did these change over time? Were there later introductions of plant species from other parts of India or from other nearby regions such as China and Southeast Asia?

There are a number of specific objectives to address these questions. To identify the seed crops present in different periods and areas of Northern and Eastern India and establish whether they are indigenous or introduced taxa (see figures 1.2 and 1.3 for potential indigenous and introduced plant species). There will be a concentration on identifying crop species, which are hard to identify to species such as Indian pulses, small millets, and rice. This includes a methodological investigation of rice identification techniques because currently there are problems distinguishing wild from domestic species using macroscopic remains and phytoliths. This analysis will start to address issues of whether there are any clear changes from wild to domestic crops, or whether there are any clear introductions of some crops, or whether at this point we can not accurately distinguish this change.

Another objective is to establish evidence for on site plant use and processing of other plant resources used by the early farming peoples of Northern and Eastern India by using phytolith analysis, including evidence for additional plant species not in the seed record (e.g.: bananas, sugarcane, various curcurbits, palms, and root crops such as taro). Agricultural systems will be assessed by looking at crop processing activities and the changes in these systems in relation to changes in crop repertoire, and archaeological phase will be analysed. Investigations into crop processing are usually examined through the analysis of macro-botanical remains. In this project, both macro-remains and phytolith analysis will be used to interpret crop processing stages and crop husbandry methods. Combining macroscopic remains and phytolith data can add to the interpretations by filtering out some of the negative effects of organic preservation problems (Harvey & Fuller 2005). A close examination of the weed species present in the samples will also be conducted to examine agricultural practices in more detail.

The chronology needs to be refined for the early farming communities in Northern and Eastern India and the antiquity of crop species will be established through direct AMS dating. There is much controversy over the dating of early agricultural sites in the Gangetic region of India and there is a complete lack of any firm chronology for Orissa. Therefore, having the newly excavated archaeobotanical material dated will enable these issues with the chronology to be addressed and allow a better understanding of the agricultural developments in these regions.

The early farming communities of Northern and Eastern India will be considered in relation to the archaeological record of other parts of India, including specifically the evidence for early agricultural systems and plant domestications, and assess the likelihood of independent agricultural origins in Northern and Eastern India.

The evidence from Northern and Eastern India will also be examined in relation to explanations for the origins of agriculture that have been proposed from other world regions such as the Near East, New World tropics, and Eastern North America. An assessment of current theories of agricultural origins will be conducted in relation to how these theories can be applied to India. Looking at pathways towards agriculture for other world regions will help to assess the current and new evidence from India.

Finally, the differences of using macroscopic and microscopic plant remains (phytolith analysis) will be evaluated in terms of their use to addresses the questions relating to agricultural development. What are the strengths and weaknesses of each technique? This will draw on the ability to identify plant species and plant parts using these methods and how this can effect the interpretations drawn in this project. How much do preservation problems affect the interpretations made using macroscopic remains?

The theoretical issues surrounding this thesis are discussed and assessed in chapter two including an examination of the approaches used to try to identify early agricultural systems. Chapter three will go on to discuss the geographical setting of the thesis. This will include a review of the modern day landscapes, geology, soil, climate, and vegetation types. Potential crops that may be found during this investigation are discussed including where these may have come from originally. There is also a brief introduction to modern day minority tribal groups and their traditional subsistence practices. Chapter four discusses all of the currently published archaeological and archaeobotanical data for the regions of study. This chapter tries to establish the pattern of early agricultural communities that is currently available and draw out specific issues that need to be addressed further in this thesis. In chapter five, the methodology used for this thesis in the field and in the laboratory is discussed and then in chapter six rice identification methods are examined and a new study of reference material is reported. The results are presented and discussed in terms of the identifications that can be made for the ancient rice remains from India. Full results of the macroscopic and phytolith analyses are presented in chapter seven and then finally these results are discussed and interpreted in chapter eight.

Chapter 2

Trajectories towards agriculture: the development and spread of agricultural communities and early patterns of subsistence

2.1 Questioning the origins and spread of plant cultivation

The origin of agricultural communities continues to be an important question within archaeology whatever world region is being investigated. Why humans decided to begin farming after such a long period as hunter-gatherers is still of great interest. Recently, the majority of this work has concentrated on regional studies emphasizing when, where, and what. Hence, much less attention has been paid to the questions of how and why this transition occurred except for studies in the Near East, which are heavily theorized. Many of the established theories were developed when little data was available and therefore the newly acquired data may not fit well with some of these models. It is also not always clear what aspect of agricultural origins is being addressed by some models, for example, whether it is the onset of plant cultivation or sedentary life that is being explained. Therefore, this makes the comparison of such models challenging and some may only relate to certain geographic regions and others to all transitions. Harris (1973) summarises that there are two approaches: i) the generalizing cultural evolutionary approach - to understand transformations from one major level to another in people's overall cultural progress; ii) particularizing culture-historical approach – to reconstruct the actual sequence of events that took place in specific locations at known times. These are essentially the two ends of the spectrum in terms of the approaches to archaeological research termed nomothetic (comparative) and ideographic (regionally focused) (Trigger 1989).

These approaches are applying either a regional focus or a more general world view of the transitions towards farming societies. The amount of evidence available will determine which of these approaches is more readily taken. Generalised models suit areas that lack data, whereas the more regionalist approach is only feasible when there is enough evidence to be more specific about sequences in a certain regional area. Applying general models is particularly difficult because it is becoming more and more apparent from new data that the transition to farming in many parts of the world happened at different times and under different circumstances. This means that a one-size-fits-all model is not appropriate. It seems a much better approach to assess the situation on an individual basis for specific regional areas and for specific prehistoric groups before considering similarities and differences with other situations.

There are a number of common themes in theoretical studies based on external or internal (stress or non-stress) factors affecting the hunter-gatherer groups that could lead to a shift towards plant cultivation. The majority of these models have a central factor, which is the main cause for the change. This does somewhat over simplify the situation and it is likely that the transition occurred for a number of reasons, which are different in different places and situations. These factors that have become central focuses of theories can be environmental, climatic, demographic, biological, or social. Here, a number of these models will be reviewed and critically assessed for their use in Indian archaeology. The transition to farming communities in India is still known from rather scarce evidence and this will hamper the application of some of the models. Although, it will be as interesting to discover that some of the models do not fit the current data as it will if some of them fit well. There is likely to be a very complicated transition to agricultural communities in India because the region is so geographically vast and there are a number of different prehistoric groups, which may all have different pathways towards agriculture. There is also likely to be some indigenous development of agriculture, as well as the later introduction of domestic plants from other regions. When the introduction of these taxa occurs, how this happens, and what this means for the prehistoric peoples' everyday lives, is of equal importance to the development of indigenous agriculture because it demonstrates another significant social change within the early farming communities. It must also be remembered that the domestication of plants is only one aspect of the social and economic transformation of society that accompanied the change from food procurers to food producers.

2.1.1 Defining domestication

There are certain terminological difficulties when discussing the transition from food procurement to food production therefore it is important to define the definitions used here. As Harris (1996) points out, there is little agreement over the terms used to describe the development of agriculture. Researchers use the terms agriculture, cultivation, horticulture, domestication, and husbandry in different ways and this has led to misunderstandings in the literature. Harris (1989, 1996a, 1996b) suggests that these terms can not be used autonomously and should be thought of as an 'evolutionary continuum of people-plant interactions'. He has constructed a diagram to show this change over time and a modified version of this can be found later in this chapter as figure 2.1. This diagram shows a progressive sequence from food procurement of wild plants to the cultivation of wild plants on a small scale and then on a larger scale and eventually the step to crop production, which is termed agriculture and involves domesticated plants. Ford's (1985) continuum of categories for the stages of food production is similar to Harris's model but has some subtle differences. He does suggest, like Harris, that these are interacting categories although he uses the term incipient agriculture for the beginnings of plant cultivation. He agrees that domestication should be used for the genetic change of the plant. There are differences in the definition of food production as Ford suggests that food production is the deliberate manipulation of plant species by humans including in this the protective tending of wild plants, where as Harris (1989) regards this activity as part of food procurement not food production.

There are a number of problems with both of these sequences. Firstly, they suggest a uni-linear progression, which is obviously not the case because not all agricultural developments would be the same. This is however, pointed out by Harris (1996: 4) and he states that this diagram is not meant to imply that all domestications have a similar pathway. This is a problem that is raised by Yen (1989) as he points out that there is an assumption with these models that hunting-and-gathering is a transitional state rather than a choice of subsistence strategy. Yen proposes that food gatherers can be seen to "domesticate" the environment by manipulating it much like agriculturalists would modify it to produce their crops. Therefore, there are two parallel forms of food production (Yen 1989: 71): i) the intensification of foraging through social development including activities such as the use of fire to encourage re-growth and the tending of wild plants; and ii) the technological development of agriculture through more successively intensive methods narrowing the species to specific environments. These are joined later by a third parallel, which is the development of state agriculture that is producing for a surplus. There can be a progression from one stage to the next but these three modes of subsistence still exist side by side and are specific subsistence choices.

The second issue with Harris's model (1989, 1996) is the placement of domestication within this sequence. His model implies that to have agriculture there needs to be a genetic change in the plant. This excludes some forms of horticulture from the definition of agriculture because some crops are not produced on large scales and never become domesticated in the genetic sense such as root and tuber crops. Hather (1996) suggests that domestication needs to be removed because it is not a single event but a continuous process occurring under selective pressure. This leaves a sequence from wild procurement to complex agricultural systems. Cultivation begins when the plant is being planted and managed where as agriculture begins when this process is relied on for subsistence. In a sense, it is not domestication that we should really be looking for but the signs of the beginning of cultivation because ancient people would not be interested in domesticating the plant as such but manipulating it to yield more produce whether this kept it wild or forced it to change genetically.

A different way of looking at the definition of domestication is proposed by Rindos (1980, 1984). In Rindos's definition, domestication can be any symbiotic relationship between plants and humans. This model of co-evolution proposes three types of domestication. These do not form an evolutionary process as they can all occur at the same time. Firstly, incidental domestication is the relationship between non-agricultural societies and the plants that they feed on. The plants do not have to be domesticated and they take advantage of human dispersal and protective behaviour that increases their fitness. This is like the wild plant procurement stage of Harris's (1989, 1996a, 1996b) model. Secondly, specialized domestication sees changes in the behaviour of the agent. These are specific behaviours that enhance the success of the plant. Humans become dependent on certain plants for survival. This includes the storage, planting, and protection of plants by humans. This would be the cultivation stage of Harris's model but Hather would call this agriculture because of the humans dependence on the plant. Finally, agricultural domestication is the establishment and refinement of systems of agricultural production. This is what most scholars would term domestication and is where the genetic change occurs (Harlan 1995, Zohary & Hopf 2000).

Rindos, therefore, is encompassing the very beginning of people-plant relationships in his definition of domestication, i.e. most hunter-gatherers. The focus of many scholars on the genetic change definition of domestication stems from our ability to recognise morphological changes in the plant but this really only recognises the end of the development. It is much harder to recognise wild cultivation archaeologically but this must be attempted if we are to progress in our knowledge of the full transition to complex agriculture of genetically domestic crops. This has been attempted through the analysis of arable weeds such as demonstrated at Abu Hureya (Hillman et al. 2001) and argued for PPNA sites (Willcox 1999, Colledge 2001).

This thesis will follow the majority of scholars (Harris 1989, 1996a, 1996b, Smith 2001a) for using the term food procurement to refer to collecting wild food resources and the term food production will be used to describe any form of production from low-level production of wild species to intensive agricultural systems. The tending of wild plants will be included in food procurement as has been done by Harris (1989, 1996a, 1996b). Cultivation will be used for any conscious human actions on the plants, such as planting and weeding, to increase its production. Agriculture can refer to either wild production or the production of domestic crops but does define a more complex subsistence system (Hather 1996). The terms domestic and domestication refer to plants that have genetically changed and therefore rely on human intervention to reproduce.

2.1.2 Centres and hearths

The path of studies concerning agricultural origins has been continually influenced by the founding work of De Candolle (1886) and Vavilov (1926). While De Candolle (1886) attempted to locate centres of domestication based on botanical knowledge, ancient texts, and linguistic inferences, it was Vavilov (1926) who led the first of the modern botanical approaches to the geography of agricultural origins. Vavilov's theory of 'Centres of origin' concentrates on when and where agriculture first happens. He mapped the distribution and degree of genetic diversity of crops throughout the world. Initially, he identified five places of independent primary domestication based on areas of high plant diversity, of which India was one, and this later developed into twelve centres. His theory is now discounted because it is clear that high plant diversity can occur in different areas to plant domestication and early agriculture (Harris 1996a). However, many theories have been developed from Vavilov's and the idea of a 'Centre' is still prominent in most literature on agricultural origins (Sauer 1952, Zhukovsky 1970, Harlan 1971, Hawkes 1983, MacNeish 1991, to name just a few!). This idea of 'centres' of origin (Vavilov 1926) is rather outdated but still influences theories because it focuses on the major crops used by the western world today. This idea should be abandoned as some form of indigenous agriculture probably occurred on most continents because many regions have wild relatives of crops in their regional flora and therefore specific food stuffs will develop according to the local environment. In some regions, such as in South Asia, these wild relatives have been under-studied. In addition, archaeobotanical approaches have been hampered because of preservation problems or lack of archaeological investigations. Domestication may have happened many times in some areas depending on the availability of suitable plants and appropriate cultural conditions. The likelihood of one single event of domestication for each plant species is also rather dubious and this could have occurred in different geographical locations across a wild species range. Therefore it depends to some degree on how large the distribution of the wild progenitor is to the likelihood of more than one location of domestication. The transition to agriculture should be seen as a scale of development with many stages much like that suggested by Harris's evolutionary classification of systems (Harris 1996b) although this does not mean there is only a single, recurrent uni-lineal pathway.

However, the majority of the models for agricultural origins do concentrate on the few better studied centres of origin, which are often sources of major crops of the modern age. These regions are South West Asia, South America, and the Far East as well as North America. Few models have been applied to or developed from evidence from the Indian subcontinent and this is largely due to the lack of archaeobotanical and archaeozoological data currently available for the periods needed in the region. An early study that does relate to the Indian subcontinent is the model developed by Sauer (1952). He suggests the idea that root and tuber cultivation preceded seed cultivation and this has long been an influential theory for tropical agricultural origins (Heine-Geldren 1923, Sauer 1936, 1952, Nakao 1966, Harris 1969, Lathrap 1977, Piperno & Pearsall 1998). The early theoretical work of Sauer (1936, 1952) concentrates on 'hearths of domestication', which are found in areas of marked diversity of plants and animals, much like Vavilov's 'centres'. The two hearths, which Sauer focuses on, are South America and Southeast Asia. This includes India as part of the Southeast Asian hearth. His theory was not particularly well tested and the idea of hearths in the Vavilov (1926) sense is obviously outdated. Therefore many scholars have been sceptical of its content (e.g: Zohary 1970, Bender 1975, Harris 1977, MacNeish 1991) but there are some interesting points that can be drawn from the model.

The hearths of domestication were suggested by Sauer to be very lush and therefore he proposes that cultivation did not begin out of a shortage of food but because these people had time to experiment. This is a very different view to that proposed for most of the Near

Eastern models, which focus on stress factors that cause food shortages to bring about the start of cultivation. However, Byrd (2005) has suggested recently that the start of the progression towards farming societies in the Near East began in a time when food was readily available.

What also differs in Sauer's model is the location of domestication. He believes that cultivation began in upland wooded areas and not in the oases of the Near East proposed by Childe (1952). He also suggests that agriculture began in sedentary villages located near to water and that the progenitors of farming were fishing folk (Sauer 1952). This difference of location may be just a geographic difference and it is probably best to interpret the location of early sites on a regional basis rather than world scale. The location will differ due to the location of available food resources and existing hunter-gatherer economic strategies. In tropical areas this may mean in more forested margins, and in drier areas, oases will be the areas with food resources. Hence, the development of farming communities in tropical regions is likely to be very different to the development in the Near East and other drier regions because of the plants available to be cultivated and the local climatic regimes. The issue of sedentism and how it relates to the beginnings of agriculture will be discussed later in this chapter.

Sauer (1952) also proposes that the people who developed agriculture would have had some previous skills that they could apply to this new activity. This has also been elaborated by Harris (1977) and this could be related to the types of foods being exploited and brought under cultivation or the tools used that could be adapted for use in the cultivation of plants as processing techniques or processing/harvesting tools (Harris 1977, Wright 1994).

An aspect of Sauer's model that has to be considered is whether hunter-gatherers could have existed within tropical rain forests without any outside influences. It is usually assumed that hunter-gatherers would have lived within many different environments in the past and modern day studies typically focus on groups that live within rainforests. However, the majority of these groups have some reliance on agriculturalists and do not rely solely on wild forest foods. Bailey et al. (1989) have proposed that rainforests could not support a group of pure hunter-gatherers because edible plants and animals are very widely dispersed. Although, it may be true that most hunter-gatherer groups today do trade forest products for agricultural foodstuffs, there are still examples of groups that are thought to live in total isolation in the recent past, for example, the Andaman islanders of the Indian Ocean (although they do exploit more than one environment). Sauer's (1952) model is based on living in forest margins and hunter-gatherer groups are usually fairly mobile exploiting a number of different habitats. A good example of this is the inhabitants of the Indian Andaman Islands. As well as exploiting forest products such as honey, tubers, yams, and fruits, coastal resources are an important part of their diet (Cipriani 1966, Bailey et al. 1989). Therefore, hunter-gatherers that exist in rain forest areas are likely to exploit a number of different environments to fulfil the requirements of their diet.

Townsend (1990) has proposed that hunter-gatherers could actually exist in isolation if they exploited the forest resources fully. She argues that Bailey et al. (1989) have underestimated the use of tree crops, including palms such as sago, which is a good source of carbohydrate. The manipulation of the forest by hunter-gatherers is another issue that has to be considered because this could still be termed as food procurement. Clearing the forest for regeneration to create patches, which will produce more edible species is only one way to alter the rainforest and solves the issue of widely dispersed resources, which are less efficient to exploit. Therefore, hunter-gatherers may be able to live in isolation within rain forests if they make full use of their environment.

Bailey (1990) has proposed that only through archaeological evidence can this debate be settled. Recent evidence that starts to disprove this theory (Bailey et al. 1989) comes from Niah Cave in Sarawak. Starch grain analysis (Barton 2005) has suggested the exploitation of a number of carbohydrate rich foodstuffs such as yam, and sago palm. This is supported by parenchyma finds (Paz 2005), and evidence for bone digging implements (Rabett 2005). Therefore, the debate is still open as to whether hunter-gatherer groups could have existed solely on forest products although this new evidence suggests that it may have been possible in the past. It is also clear that these groups could have settled within forest margins and exploited a number of different environments rather than solely relying of forest foods.

Therefore, there seems to be two streams of theoretical influence within the question of agricultural origins. The oasis-based hearths initially proposed by Pumpelly (1908) and later developed by Childe (1952). This specific pathway is discussed later in the chapter relating to climate change factors. This theory is usually used for the Near East and relates to deficiencies in the environment to provide resources. Many scholars have followed this pathway towards agriculture such as in Near Eastern studies in various modified forms (Bar-Yosef & Meadows 1995, Smith 1995, Hillman et al. 2001, Willcox 2004) and also in the Far East (Cohen 1998, Yasuda 2002a). The opposing theory base comes initially from Sauer (1952) and is based on rich forested environments providing stability for the development of cultivation. This theory is popular with scholars that research tropical environments such as parts of Asia and South America (Harris 1969, 1972, Lathrap 1977, Hather 1996, Piperno & Pearsall 1998). It is clear from these two opposing theory bases that there is not only one kind of environment in which cultivation and later agriculture could have developed. These models are based on different regions and therefore have different expectations for the beginnings of cultivation.

2.1.3 Tropical hearths: vegeculture.

The most important point to come from Sauer's (1952) theory is his suggestion that root and tuber agriculture predated seed agriculture. He explains this using Southeast Asia, where he perceives taro cultivation as a pre-requisite to rice domestication (Sauer 1952: 28). Even though it is unlikely that root and tuber agriculture brought about rice domestication in Southeast Asia, as the archaeology now suggests that this occurred at least once in South China and then spread to Southeast Asia (Glover & Higham 1996), roots and tubers probably played a key role in the transition to agriculture in the tropics. The cultivation of roots and tubers probably did precede seed cultivation in Southeast Asia and rice was an introduced crop in to this area rather than a domesticated one (Gorman 1969, 1977, Golson & Hughes 1976). The presence of early cultivation of tuber crops is also likely in Eastern and North eastern parts of India although in these regions rice could have been domesticated locally within India whether in the East or North of the country.

Harris (1969) has also suggested that root and tuber agriculture is fundamental to our understanding of plant domestication and the beginnings of agriculture. However, the study of these crops has been neglected and therefore our picture of agricultural origins as a whole lacks this aspect, which may indeed be some of the earliest cultivation in the world. Investigations on the whole are much fewer in the tropics but when studies are conducted they are hindered by the lack of organic remains present. Bio-archaeological studies in tropical zones are hampered by the fast turn over of carbon, which results in the decay of archaeological remains at a much faster rate than in temperate or semi-arid regions (Hather 1992, Piperno & Pearsall 1998). Therefore, plant macro-remains and other organics are hard to recover and generally found in lower densities in tropical regions. Consequently datasets are limited, fragmentary, and difficult to analyse. In addition to preservation issues, only a small amount of work has been conducted on how to identify roots and tubers in archaeological deposits and many more studies are needed. Macroscopic preservation of roots and tubers is as rare as other macro-remains on tropical archaeological sites, and added to this, poor identification methods, makes recognition of this material very challenging. Consequently, different approaches are needed to overcome the problem of identifying tropical plant remains (Hather 1992, 1994, 1996, Piperno & Pearsall 1998). Techniques such as phytolith analysis, starch grain analysis, and the identification of roots and tubers through parenchyma fragments should be combined with the more traditionally used archaeobotanical methods of macro-remains and palynology to establish detailed bio-archaeological datasets for past tropical agriculture.

Harris (1977) suggests that vegeculture was an obvious choice for the beginning of cultivation in the tropics because it was already being exploited and therefore the technology was available. Root crops have the ability to store starch over long dry and cold seasons and when matured can be left in the ground until needed, thus preventing rotting. Root and tuber crops are also quicker to propagate because they are grown from cuttings and do not remove as many nutrients from the soil as most seed crops. The harvesting of root and tuber crops would have resulted in discarded parts being left and therefore the regeneration of some of these would be observed. Harvesting therefore may actually promote proliferation. Andersen (1997) suggests that the collection of wild tubers using digging sticks, by Native Californian's, actually maintains the production of the food plant. Harris (1977) suggests the move to cultivation would have been a simple step and started as a minor activity of hunter-gatherers, which later developed into a specialised mode of production once these groups came under stress. Therefore the initial steps of plant domestication in the tropics could be unconscious acts that were later developed in to a deliberate agricultural system.

Sauer's early work has also influenced Japanese scholars of whom Nakao (1966, see Sasaki 2002 for English summary) was the first to suggest vegeculture as the basis for farming culture. He classified agricultural systems in to three types: Mediterranean – the Near Eastern seed crop package including wheat and barley; Savannah – semi-arid zones of India and Africa including rice and millets; Vegeculture – wet tropical zones including bananas, taro, yams, and sugarcane. Nakao and later Hotta (1983, 1999) also believed that root and tuber agriculture originated in Southeast Asia (including Eastern India).

There are two aspects to the development of root and tuber agriculture in Asia. One is, as discussed above, the indigenous development of root and tuber agriculture in Southeast Asia and the other is the development from or introduction of rice agriculture to this initial subsistence system. Tanaka (2002) has suggested that rice growing techniques closely resemble those used in root and tuber crop cultivation. Rice transplantation techniques are used predominantly in East and Southeast Asia and this is similar to the individual selection, harvesting, and planting of root and tuber crops. These systems are much more individually focused than the community based wheat and barley sowing methods (Tanaka 2002). This may reflect the differences between the development of *indica* and *japonica* types as this system relates more to inundated rice of Eastern Asia rather than the rain-fed rice of South Asia.

It is also suggested that rice agriculture in India is more like the wheat and barley system (Tanaka 2002). However, this model does not account for the later introduction of wheat and barley agricultural systems in to India and probably does not relate to the initial systems of cultivation. Rice was grown in India before wheat and barley were introduced from North-western parts of the Indian sub-continent. Therefore, early cultivation systems may have resembled root and tuber cultivation systems before this time. Evidence for this may be found in the material culture associated with these early agricultural communities.

Digging sticks are the only piece of technology specifically developed for root and tuber cultivation (Sasaki 2002). Evidence for ancient digging sticks is lacking because of preservation issues but ringstones may be associated with them. These ringstones are found throughout Northern India in pre-ceramic/Mesolithic contexts onwards and have been recovered from the prehistoric sites of the Ganges Valley and in the state of Orissa (for examples see Sharma et al. 1980, Mohanta 2002).

Root and tuber cultivation must have played a significant role in the development of agriculture in tropical regions but has so far been predominantly overlooked. This development may have also influenced the beginning of rice cultivation in some areas and the spread of rice in to Southeast Asia was probably introduced in to an existing root and tuber cultivation system. However, many more studies are needed to confirm the existence of early root and tuber cultivation in the Indian subcontinent and this question cannot yet be answered, as insufficient amounts of charred tuberous material has been recovered through flotation from the sites analysed in this thesis.

2.1.4 Climate change

The majority of other models differ from Sauer's (1952) non-stressful (or "food choice") development of agriculture and promote the importance of external factors that cause stress resulting in food shortages. Climatic and environmental change is a very popular model ("food stress") because of the vast amount of work focused on the Near East. Childe's (1952) oases model, based on Pumpelly's (1908) earlier work, suggests climate change as the prime mover for cultural changes and specifically agricultural origins. At the time this theory was developed, there was reasonably good evidence for climatic changes at the end of the Pleistocene in Europe but no evidence from South West Asia. Childe (1952), however, proposed that Post-Pleistocene desiccation led to the concentration of people, beast, and plant at oases. He said that this might promote a symbiosis between people and beast implying animal domestication, and plant domestication was also suggested. He implies that this close association would inevitably lead to the discovery of agriculture assuming that it was an obvious choice. This is still an assumption that is made in many studies today such as in early agricultural sites in China where the discovery of any rice is usually considered to be domestic and therefore agricultural. Wild gathering as well as wild cultivation, especially for plant species such as rice, should also be considered for these sites, which may have previously been considered to show domesticated plant agriculture.

Childe's model set a trend in Near Eastern studies, which is now dominated by models of climate and environmental change (Bar-Yosef & Meadows 1995, Smith 1995, Harris 1996, Willcox 1999, Hillman et al. 2001). This factor is now widely accepted as the predominant cause of the emergence of agriculture in this region. The Near East benefits from detailed palaeoecological studies that have revealed an environmental deterioration as a result of the Younger Dryas episode from ca. 11,000 to 10,000 B.P. (van Zeist & Bottema 1977, Bottema 1986, Baruch & Bottema 1991, Baruch 1994). The cooler and drier climate of the Younger Dryas resulted in most of the exploitable natural resources declining in this region. Hillman and his team's work (Hillman 1996, Hillman et al. 2001) at Abu Hureya is a good example of how climate change has been used to explain the beginning of cultivation and subsequent domestication of cereals in the Near East. Detailed archaeobotanical investigations revealed an increase in arable weeds around 11,000 B.P. (uncalibrated), which led to the conclusion that the people of Abu Hureya had begun cultivating wild cereals (annual wild rye and wild wheats). This coincides with the beginning of the Younger Dryas period, which caused declines in many wild species through a phased process, and it was therefore concluded as the factor that greatly influenced the start of cultivation in this area. Moving from Abu Hureya was another option for these peoples but Hillman (Hillman *et al.* 2001) suggests that this was not done because it was the richest area for natural resources and therefore other areas would have been more depleted during the Younger Dryas.

The Near East presents an example of a major climate shift that has a detrimental effect on the environment and consequently stresses sedentary hunter-gatherers causing the beginning of cultivation. However, not every world region has agricultural origins that coincide with the beginning of the Holocene. Models that promote climate change as the prime mover, tend to be better suited to the datasets of the 'centres of origin' where processes are focused in very tight delimited ecological zones rather than the more dispersed and long-term emergence of agriculture in the tropical 'non-centres' (Harlan 1971) where ecological zones are more extensive or patchily distributed. Agriculture in India appears after the end of the Pleistocene and therefore the accompanying environmental change did not affect the hunter-gatherers to the same degree as those in the Near East but these groups may have been affected later by Holocene fluctuations in monsoon rainfall (Fuller & Korisetter 2004). The emergence of agricultural societies in India seems to have occurred over a much longer temporal period because interaction occurs between hunter-gatherers and farmers to the present day. The introduction of agriculture from other regions into parts of India also plays a role in the overall development of agriculture, therefore climate change can not explain all the moves towards plant cultivation. Again, it is better to approach this transition on a more regional basis especially in such a large sub-continent as India.

2.1.5 Population pressure

Another model that promotes a stress-induced development of agriculture is the suggestion of population increases and pressure creating food shortages. This factor is also used in Near Eastern models. Cohen (1977a, 1977b) argues that population growth and pressure is a significant trend among pre-agricultural peoples that led to the beginning of agricultural societies. His model is based on earlier work by Boserup (1965), who suggests the progression to more complex agricultural technologies is a response to growing population. The problem with population models for the emergence of agriculture is their general nature. These models are vague and it is hard to prove population growth and its link to agricultural origins. Keeley's (1995) study of hunter-gatherer societies suggests that population pressure alone only leads to socio-economic complexity not proto-agriculture. Rosenberg (1998) suggests that population pressure may in fact induce territoriality and sedentism although this may only occur where resources are available in concentrated patches.

Many of these population based studies have focused on the ecological concept of carrying capacity, which relates to the maximum level of consumption of any resource that an environment can tolerate. However, this idea is not relevant to humans because of their broad diet (Cohen 1977a). Humans rarely exploit all of the resources available to them and therefore if there is a scarcity of one resource then they can shift to another. It therefore does not take into account how foragers respond to changing resource densities (Piperno & Pearsall 1998).

Another factor of the population model is its uni-linear approach to the process of agricultural origins. It assumes that every hunter-gatherer group grew in number and therefore became agricultural. This is not true for many areas where hunter-gatherers persist to the present day such as in India and Africa. There are also cases of newly agricultural groups returning to foraging in times of famine if the appropriate knowledge is still available (Harris 1980). Piperno & Pearsall (1998) think that population pressure was not a significant factor in the New World tropics because the area was settled by so few people but populations may have increased later due to horticultural intensification. Therefore, models based predominantly on population may have little relevance to studies of agricultural origins in the tropics. However, population growth may have played some role in combination with other factors in some parts of the world.

2.1.6 Darwinism and domestication

The application of Darwinian evolutionary theory to the question of origins of agriculture has brought a more biological explanation to the debate. Rindos (1980, 1984) believes that unconscious selection was the pre-eminent force behind the domestication of plants and animals. He suggests that consciousness is not needed for domestication and this model deals directly with the process of domestication of the plant or animal. This is also proposed by other scholars (Harlan 1995, Zohary & Hopf 2000, Gepts 2004). Co-evolution is the evolutionary process in which the establishment of a symbiotic relationship between organisms increases the fitness of all and brings about changes in the traits of the organisms. Rindos (1984: 99) does not suggest this is the cause of domestication but proposes that it is a pre-requisite to agriculture. As discussed above, Rindos has a rather different definition of domestication to other researchers, however his definition does encompass the whole spectrum of change. Rindos (1984) is promoting an unconscious domestication of plants but he is not denying the initiative of humans. They could have selected for pleasing attributes or those that were useful to them. He does emphasize the point that these people could not have foreseen an agricultural economy because no such thing had previously existed at that time (Rindos 1984, Watson 1995). This is an important point to keep in mind when thinking about the transition to agriculture because, even though hunter-gatherers would have had an in depth knowledge of their environment and the plants in it, they had no knowledge of agriculture, nor the genetic architecture of the domestication syndrome that the world ultimately selects. Therefore, it is quite right to expect the very initial steps towards agriculture to be unconscious and then human initiative would have taken the next steps. Rindos's theory is, however, a one sided view of the development of agriculture focusing on how this process happened. It does not account for social changes in hunter-gatherer society or the external factors of climate and environmental change, which may have allowed for this development in the interactions between man and plant. Hence, it does not consider why this happened and Rindos goes further by saying that to ask why humans began close associations with certain plants is a question without real meaning (Rindos 1984: 141). This is one way of avoiding the hard question of why humans began using plants but there has to be a cause for this change even if it is that the humans wanted to use the plants.

Initially, if we are looking at food procurement, they had a dietary need for the plants and probably experimentation was the key to deciding what was edible and what wasn't. Humans must have been the driving force but a change to cultivating these plants could have many causes. Farrington & Urry (1985) suggest that plants have specific cultural values and this is why they are exploited or produced. This can be for a number of reasons such as for material culture, decoration, and medicines, as well as food. Selection of food resources will initially be based on edibility but cultural habits and preferences are also likely to influence choice and the amount of effort given to collection or production of certain food stuffs. Therefore, avoiding the question of why these plants are being exploited is to miss out a vital part of the investigation even if it is probably the hardest issue to address.

2.1.7 Evolutionary ecology

Another application of Darwinian Theory is evolutionary or behavioural ecology, which has focused on why these associations took place and what circumstances led humans to select certain species for exploitation (Smith & Winterhalder 1992, Piperno & Pearsall 1998). Evolutionary ecology is the application of natural selection theory to the study of adaptation and biological design in an ecological setting (Winterhalder & Smith 1992). When this involves behaviour it is called behavioural ecology. They both use simple mathematical models to understand complex systems. Behavioural ecology differs from Rindos's co-evolutionary theory by emphasizing the decision making of animals capable of flexible and learned behaviour. The key principle behind behavioural ecology is optimization, which means that an individual relates to their environment in such a way to maximise their reproductive success (Shennan 2002). The humans or animals have the capacity to adjust quickly to varying ecological circumstances. The intentionality of the development of agriculture, which is a sticking point of most theories, is less problematic when applying behavioural ecology because human behaviour is seen as the motivating force (Piperno & Pearsall 1998). Optimal foraging theory and in particular the Diet Breath and patch selection models (MacArthur & Pianka 1966, Emlen 1966, Charnov & Orians 1973, Winterhalder & Smith 1981, 1992, Smith 1983, Keegan 1986, Hawkes & O'Connell 1992, Winterhalder & Goland 1993, 1997) have been applied to hunter-gatherer strategies and also less frequently to agricultural subsistence.

These foraging models contain three components: decisions, currencies, and constraints (Kaplan & Hill 1992). The decisions are the foraging problems that are being analysed. The currency defines the measurement scale for evaluating the effects of the decisions. This can be a measure of energy, protein, survivorship, or fertility. The constraints are all of the other terms that are in the model. These models investigate what happens when foragers encounter resources and have to decide whether or not to pursue this resource or move to find another one. These models can be formally tested using ethnographic studies of modern hunter-gatherers and horticulturalists. This has shown in supporting propositions that energy is a useful currency to use and that energetic concerns are major constraints on foraging decisions (Piperno & Pearsall 1998:17, Shennan 2002).

This approach has been used in some cases to try to explain the transition to farming communities (Hawkes & O'Connell 1992, Winterhalder & Goland 1997, Piperno & Pearsall 1998, Hawkes et al. 2001). In their examination of the origins of agriculture in the lowland Neotropics, Piperno & Pearsall (1998) suggest that behavioural ecology and particularly the diet breath model is the most appropriate way to explain the transition to plant cultivation. They rely heavily on the diet breath model because they believe that it makes a number of valuable predictions (Piperno & Pearsall 1998: 17-18): "i) resources will enter the diet as a function not of their own abundance but of the abundance of higher ranked resources; ii) as the abundance of higher ranked resources decline and foragers begin to do better by investing less time in them and more time handling lower ranked resources; iii) the foragers will now choose a broader diet because it results in higher return rates than could be achieved by more searching; iv) the reduction in search time will permit greater investments in storage and food processing, which adds to the nutritional quality of what is eaten and extending the use life of the food item; v) the broader diet and decreased search time will also lead to smaller foraging radii and may increase residential stability; vi) changes in diet breath may result in human demographic change, whose direction is dependent on the characteristics of the resources newly incorporated in to the diet". This bares close resemblance to Flannery's (1969) broad spectrum revolution and also addresses the issues of sedentism and population pressure.

There have been arguments as to whether these models can be applied to humans because humans have free will and therefore may have different goals to those assumed by the models. These models take no account of cultural choices as mentioned above, which may play a large role in the selection of certain foodstuffs and other materials. Therefore, optimal foraging theory may not be applicable to archaeological studies and is probably better left to ethnography. Smith (1983: 629) proposes that foraging theory is useful for generating hypotheses but when models are applied to archaeological data they are inherently limited by a lack of direct measures of either foraging costs or harvest rates. To actually apply the models to archaeological situations, ethnographic analogies or experimental data can be used but these come with their own limitations. Bettinger (1983: 640) adds that uncertainties about tactics are compounded by estimates of search time within specific patches and the distribution of patches within the habitat. This results in the rapid accumulation of uncertainties even in simple models and makes optimal foraging theory no more than a rough analogy in archaeology. He again suggests that it is best used as a generator of hypotheses rather than a source of rigorous quantitative models (Bettinger 1983).

Shennan (2002) suggests that these models are in fact useful for addressing archaeological problems. They should be used as hypotheses and seeing where the model does not fit is very interesting. This can lead to interpretations of why this might be and therefore determine specific behaviours. For example, the behaviour of men usually fits optimal foraging models because they select hunting, which maximises outcomes. Women tend to fit a lot less to the idea of optimisation than men because their activities do not maximise their efforts (Shennan 2002: 147). Therefore, behavioural ecology may help to determine agricultural origins if the right methodology is applied. Appropriate archaeological evidence needs to be found that can be used to test and refine these models and then there is a chance that they can help to determine past behaviours.

2.1.8 Broad spectrum revolution

The broad spectrum revolution (BSR) was initially proposed as a period that saw the broadening of the resource base of foragers and this process was involved in the transition to animal herding (Flannery 1969). The BSR was explained as the shift away from hunting large ungulate mammals to the exploitation of birds, reptiles, fish, invertebrates, and previously ignored plant resources. Since Flannery proposed this theory for the development of agricultural settlements, much more evidence has come to light but this theory is still common in the literature (Clark & Yi 1983, Stiner et al. 1999, Stiner 2001, Munro 2004, Weiss et al. 2004). Initially, Flannery placed the BSR in the middle of the Upper Palaeolithic about 20,000 BP and it was proposed to be closely linked to the emergence of pre-agricultural settlements. However, recent studies have pushed this date further back as far as the Middle Palaeolithic for faunal remains (Stiner et al. 1999, Stiner 2001) and to 23,000 BP for plant remains (Weiss et al. 2004) and therefore it does not have as much relation to early villages as was first suggested in the initial theory. The plant remains evidence from Ohalo II does demonstrate that a large variety of different species were exploited especially grasses but this does not necessarily support the BSR theory as there is no earlier evidence to compare it with to demonstrate a 'revolution'. Edwards (1989a) has suggested that if all of the evidence is compared for faunal and floral remains from the Mugharan period to the PPNB then it is clear that there is no BSR in the Middle or Upper Palaeolithic and therefore it can not be used to address the issue of the development of agricultural settlements. The evidence in fact suggests that a broad spectrum subsistence pattern was normal throughout much of the Upper Pleistocene in the Levant and there was no visible increase in faunal diversity in this period (Edwards 1989a: 240-241). Therefore, there is no relationship between broad spectrum foraging and the rise of food production.

2.1.9 Competitive feasting

Another theory, which uses an internal factor, this time a social one, to explain the transition to plant cultivation, is Hayden's aggrandizer feasting model (Hayden 1995a, 1995b, 1998, 2001, 2003). This theory is very different to other models of agricultural origins as it suggests certain plants were domesticated first of all as luxury foods. This is in contrast to the normal suggestion that early plants were staple crops. The feasting model suggests luxury foods were developed for consumption in feasts. Hayden (2003) suggests feasts are important for the consumption of surpluses and there is significant competition to display wealth at the most important feasts. He uses ethnographic examples from Southeast Asia to explain how rice was first domesticated as a luxury food (Hayden 2003). However, he suggests that rice comes from wild hill rice, which does not fit well with current archaeological and genetic evidence (see discussion in chapter 6 below). The wild progenitors of rice (*Oryza rufipogon* and *Oryza nivara*), which are confirmed by genetic studies (Chen et al. 1993, Cheng et al. 2003), are both lowland species (Vaughan 1994) and therefore it is more likely that rice was domesticated at lowland sites, which is also suggested by the current archaeological evidence. Hayden (2003) proposes a number of reasons why rice would be a luxury food including its good taste, its use as alcohol, and that rice is used in rituals and the ideological life of modern hill tribes. Although he is quite right that rice is used in rituals today, this does not mean that it was a luxury food or was given a prestigious status that allowed it to be domesticated. Rice is a staple today as well as being used in many rituals so the link of luxury food and rituals is not the only possible explanation. He argues that because we see ethnographic examples of this practice today there is no reason to think it was different in the past. This is a large assumption, which is equally likely to be untrue. It can not be assumed that what happens today was also occurring in prehistoric times (Gould 1980, Trigger 1995). It is also hard to find direct evidence of feasting on archaeological sites therefore Hayden's theory has many flaws and deserves a cynical review.

2.1.10 Addressing agriculture spread

As well as questioning the development of indigenous agriculture, the spread of established crop packages or single crops in to areas with no previous cultivation or in to areas with existing indigenous cultivation systems needs to be addressed. The beginnings of agriculture in some world regions, such as Europe and Egypt, was not the result of local domestications but instead a diffusion of domestic plants and animals or the immigration of agricultural communities from other regions. Less attention has been paid to regions that had some local development of domestic species, sometimes suggested to be of minor importance, which was later replaced with another agricultural package developed elsewhere (Fuller 1999). Examples of this would be the Eastern Woodlands of North America and South India.

At the forefront of discussion on this particular topic is frontier theory, which considers the colonisation by agriculturalists, and their interactions with hunter-gatherer groups in regions with no previous agriculture, within a single framework (Alexander 1978, 1980, 1984, Alexander & Mohammad 1980, Dennell 1983, 1985, Zvelebil 1986, 1996). There are two types of frontiers: the moving frontier and static frontier. These have been termed 'spread zone' and 'friction zone' by Bellwood (2001). The moving frontier (or 'spread zone') sees the expansion and colonisation of new lands by agriculturalists. Hunter-gatherers will react to the moving frontier and are either destroyed by the farmers through absorption or acculturation, or retreat into isolation. The moving frontier has been suggested to occur until all the usable land is taken up or until the limits of climatic tolerance of the plants and animals are reached (Alexander 1978). Hence friction is created by some kind of boundary, which restricts further movement and the moving frontier therefore stops setting up a static frontier. Interactions between hunter-gatherers and agriculturalists will occur and components of the agricultural package may be adopted by the hunter-gatherers. Static frontiers would have also existed where isolated groups of hunter-gatherers were left behind the moving frontier.

There are three models to show how the frontier moved forward and the causes of the move (Alexander 1980): i) a steady horizontal spread, which is also known as the wave of advance model caused by demic explosion (Ammerman & Cavalli-Sforza 1971, 1973, 1984); ii) a selective horizontal spread that involves hopping from place to place whether for favourable soil conditions, water, or other factors (Ammerman & Cavalli-Sforza 1971, 1973, 1984, Renfrew 1987, Van Andel & Runnells 1995, Cavalli-Sforza 1996, 2002); iii) a selective vertical spread, which are variations of transhumance (Higgs et al. 1964, 1966). The wave of advance model appears commonly in the literature on the spread of agriculture and encompasses the demic diffusion of agriculturalists (Harris 1996c, Bellwood & Renfrew 2002, Bellwood 2005). This model has also been used to explain the dispersal of languages, which in some cases is thought to be linked to the spread of agriculture such as the movement of Indo-Europeans in to Europe and the Austronesians in to Southeast Asia (Renfrew 1987, 1996, Bellwood 1989, 1991, 1996, Bellwood & Renfrew 2002, Bellwood 2005).

The wave of advance model has been applied commonly to explain the spread of agricultural communities in to Europe and specifically the spread of the Linearbandkeramick (LBK) culture. Renfrew (2002) has argued that, even though recent genetic evidence may not seem to fit the wave of advance model (Richards et al 1996, Underhill et al 2000, 2002), it in fact can explain the expansion of languages and farming, demonstrating significant gene flow between the incoming and existing populations. However, some scholars have been very critical of explaining the whole of European expansion using this model (Alexander 1978, Zvelebil 1995, 1996, 2002, Zvelebil & Zvelebil 1988). The rapid dissemination of the LBK culture, which spread from Slovenia to the Paris basin in 200 years, can be seen to contradict population pressure models such as the wave of advance model by being too fast. Furthermore, Alexander (1978) suggests that this model is inappropriate to explain the spread of any agricultural communities because it conceals the local variations that can occur by the smoothness implied by the curve and it also does not account for more than one period of frontier advance. He proposes that selective horizontal spread is more appropriate to explain the spread of the LBK agricultural communities (Alexander 1978, Barrett 1994, 1999, Whittle 1996a, 1996b, 1997, Thomas 1999).

However, the northerly and westerly expansion of pioneer farmers of the LBK from the Hungarian plain to Germany and the low countries was a complete cultural replacement and has been seen as a good example of the rapid migration and colonisation by agricultural groups (Clark 1952, Ammerman & Cavalli-Sforza 1971, 1984, Bogucki 1987, 1996, Price et al. 1995) but the role of the indigenous hunter-gatherers should not be underestimated. After 5400 BC, the LBK populations were spread through the fertile loesslands and had established permanent villages at the edges of floodplains with their characteristic timber longhouses (Hamond 1981, Bogucki 1988, Modderman 1988, Whittle 1996a) and characteristic incised pottery. These villages only leave negative features filled with archaeological deposits. These settlements had an economy of emmer and einkorn wheat, broomcorn millet, cattle, sheep, goat, and pig. It has been suggested therefore that the agricultural communities hopped from one suitable area to the next being particularly selective about the placement of their settlements. This is a form of shifting cultivation and was originally proposed by Childe (1929: 45-46). The argument for this pattern of shifting cultivation comes from the lack of tell formation (Childe 1929), the evidence for discontinuity of settlements (Soudsky & Pavlu 1972), the assumption that soils will be rapidly exhausted (Childe 1929), and pollen evidence for clearance and burning of woodlands (Wasylikowa et al. 1985, Rosch 1990). Bogaard (2002, 2004), however, suggests that this argument is open to question and her reassessment of the published data along with new archaeobotanical analysis clearly rejects the shifting cultivation model. She argues for a more permanent fixed plot cultivation system where agriculture spread through adoption rather than migration based on the analysis of weed seed data. This is in agreement with the assumption that humans would want to fully exploit their environment rather than waste it by moving on quickly (Bogaard 2004: 155). During the LBK period, crops were grown in intensive garden cultivation in fixed plots and sown in the autumn (Bogaard, 2002, 2004: 160). Manuring was also practised therefore preventing soil exhaustion and also negating the need for careful site selection because soils could always be improved.

However, this does not mean that this agricultural scheme was adopted throughout the whole of Europe and there was much the same continuation of material culture in other parts of the continent (Zvelebil 1995, 1996, 2002, Zvelebil & Zvelebil 1988). This will be discussed in more detail below.

2.1.11 Adoption of agriculture

The causes of the adoption of domestic plants and animals also needs to be considered. This can be either the adoption of a crop package in to an area previously with solely hunter-gatherers or can be the introduction of a secondary crop package in to an existing indigenous cultivation system. Secondary crop packages may compliment existing economic systems or could replace them altogether (See papers in Weber & Belcher 2003). This can again include models of food stress or food choice. Demographic and environmental/climatic change causes have been suggested in much the same way as with cases of indigenous domestication (Zvelebil 1986). However, social factors, especially social competition, seem to be favoured for the adoption of crop packages. The adoption of farming can be seen as a means of maintaining social control or the competition for status (Sahlins 1974). This includes social models such as the competitive feasting model (Hayden 1995a, 1995b, 1998, 2001, 2003) and tradeable, culturally valued foods (Farrington & Urry 1985, Sherratt 1999). Interactions between hunter-gatherers and farmers would have made new foods available and these may have been considered with some status. Zvelebil (1996, 2002) has suggested that the hunter-gatherers of the Baltic regions and North and East Europe did not see the migration of farming people in to their territories. This is partly due to the intolerance of some crops to the environmental and climatic conditions in these areas causing a natural barrier for farmers. Hence, the adoption of farming by the indigenous foragers in these regions of Europe took place through contact, inter-marriage, and socially related mobility between foragers and farmers within frontier zones (Zvelebil 2002). He proposes that demic explosion is unbelievable and any estimates of population are unreliable. The size and density of Mesolithic populations is always underestimated. Therefore, the spread of agriculture into Europe was a combination of the migration of farmers and the adoption of agricultural elements by the indigenous foragers although the degrees of input from these two sources varied by region.

2.1.12 Situating India

As far as India is concerned a number of different theories have been proposed. From its initial status as a 'centre of origin' (Vavilov 1926), it has been demoted by most scholars to be an area of agricultural introduction or at best an area with minor crop domestications (Harlan 1971, MacNeish 1991, Bellwood 2005). Hutchinson (1976) suggested agricultural communities were established by either the introduction of African crops or the local domestication of summer crops (see also, Possehl 1986). North-west India is clearly an area of predominantly agricultural introduction and it is likely that this was due to the migration of people and their crops and animals from South West Asia also with some local animal and plants domestications (Meadow 1989, 1996, 1998, Weber 1991, 1997, 1999, Weber & Belcher 2003, Fuller & Madella 2001). This began the establishment of the Harappan civilisation in this part of India. Further migration of the Harappan people and their agricultural package has been suggested for the rest of India (Chakrabarti 1999) but the adoption of the crops and animals seems more plausible due to a lack of change in material culture in most areas. The adoption of the 'Harappan' package in Rajasthan and Madhya Pradesh may be related to climatic factors (Madella & Fuller 2006).

However, the Peninsula of India is less known and this is partly due to a lack of data in some regions but also due to the likelihood of a number of areas of indigenous domestication. The origins of agriculture in South India has been addressed recently by Fuller (1999, 2002a, 2003a, 2003b, Fuller et al. 2001, Fuller & Korisettar 2004) inferring the indigenous domestication of crops as well as later introductions from a number of different regions. He has suggested that the local domestication of a number of crops happened due to climatic and environmental changes (Fuller & Korisettar 2004).

Fuller (1999) also puts forward a series of modes for agricultural origins and suggests that it is important to distinguish between indigenous and introduced agriculture. He proposes four main types of agricultural origins:

1A) Primary centres of major crops - wild progenitors of major crops are present, and the transition usually occurs during the early Holocene and there are innovations of material culture. This includes areas such as South West Asia, South-central China, South America, West Africa, and sub-Saharan East Africa.

1B) Primary centres of minor crops with "overstamping" – wild progenitors of minor crops that have been largely replaced by secondary diffusion of major crops. This includes Japan, North China, Eastern woodlands of North America, Ethiopia, parts of Southeast Asia, and South India.

2A) Secondary centres, introduced by immigrant wave (moving frontier) – crop package arrives from elsewhere and there is a full scale material culture change. Areas include Central East Europe, Thailand and Southeast Asia, Northwest South Asia, and the Iranian-Baluchistan region.

2B) Secondary centres, adopted from adjacent farmers (static front) – the adoption of crops in piecemeal fashion and in some cases material culture was also adopted. This includes Northern and Atlantic Europe, Egypt, Southwest North America, parts of India, and Central Asia.

This addresses what, where, and sometimes when agriculture occurred in different world regions but leaves out how and why it occurred. He has left these questions to be addressed at a regional level as with his work in South India. In this series, South India has been put into IB as minor millet crops were domesticated with secondary introductions of non-native millets, which over-stamped the local crops. However, this category needs to be expanded because some regions may have introductions that can be slotted into the existing system extending it rather than providing a new agricultural system altogether.

The other parts of India have been put in to 2B but this again may be due to lack of data in some cases. If India has an area of rice domestication, which is a major crop, as is proposed for the Gangetic area and Orissa in this project, it will fit in to IA but these areas may also have later introductions and therefore these areas do not fit into one specific category of Fuller's series. Consequently, this suggests again that India is rather more complex than first thought and there are likely to be a number of different transitions to agriculture depending on the local wild progenitors and influences from outside the region.

It has become clear with this review of theories for agricultural origins and spread that there are certain limitations to each of the models. The majority of the limitations relate to the general nature of the theories. This means that they can not be applied to every situation even though this may be attempted and many of the older theories were developed when very little data was available. To develop a theory for agricultural origins as a whole is over simplifying the situation that faces us. What should be addressed is the extensive and complex mosaic of many different and distinct developmental problems that occurred during this time of immense change (Smith 2001b: 202). In each region, the local environment and culture are different and this brings different plants and animals under domestication in different ways and at separate times. A much more regional approach will address the complexities in the transition to farming societies. This needs to start with the collection of appropriate data such as archaeobotanical and archaeozoological investigations. Once this has taken place at a number of sites and a chronology has been established then theories as to how and why domestication may have occurred in a specific area can be put forward. However, it is still important to recognise parallels in other world regions, which may help to develop answers to the questions involved in agricultural origins. Looking at the complex sequence of developments, not just one single part of the transition, will allow greater insight into the questions of why and how these changes took place.

2.2 Developing the trajectories of change

Many of the theories for agricultural origins focus on single causes for what is a huge social and economic change. It is much better to see this transition as a process with several key elements: sedentism, cultivation, herding, and pottery development. These elements seem to occur at different times and in different orders throughout the prehistoric world. The sequence of these elements may in fact be the key to interpreting the hard questions of how and why the transition to agricultural communities occurred. Only by examining all of these developments can we get an entire picture of the process and in particular the specific transitions that happened in different world regions or sub-regions.

2.2.1 Sedentism

Sedentism is seen as a pre-requisite to agriculture in most Near Eastern models of agricultural origins (Smith 1995, Bar-Yosef & Meadows 1995, Byrd 2005). Byrd's recent article (Byrd 2005) suggests that sedentism occurred at the onset of the Natufian period in the Near East by complex hunter-gatherers, which is supported by Munro (2004). The formation of settlements occurred at a time of optimal climatic conditions and happened in the most productive parts of the Near East. This was driven by social factors such as population aggregation, resource intensification, surpluses, and major changes in group dynamics, social interactions, and ideology (Bryd 2005). He goes on to suggest plant cultivation happened initially as a supplement to the diet because grasses were declining due to intensive exploitation and possibly environmental/climatic factors. However, some scholars suggest a more seasonal use of some sites (Edwards 1989, Harris 2002) that could also have brought about these changes. Therefore in the Near East there is definitely a move towards sedentism initially, which is followed by the development of plant cultivation.

In Harris's (1977) model, heavily based on tropical regions, a reduction in mobility is suggested as a key difference between hunter-gatherers and agricultural societies. Harris (1977) has pointed out that ethnographic studies have found links between sedentism and increases in population. He suggests that this may lead to an intensification of labour input into food procurement and consequently increasingly specialized exploitation of agricultural resources. However, there should not be a particular emphasis on sedentism as a prerequisite to agriculture in tropical regions because it is not always necessary for agricultural production. A reduction in mobility as a factor in inducing cultivation is complicated in the tropics because of the use of shifting cultivation systems. The nature of swidden or shifting cultivation suggests a degree of continued mobility even with cultivation. Swidden is a small-scale cultivation method but relies on a large amount of fallow land and therefore extensive areas are needed, which usually requires constant settlement movement (Harris 1972). Although, this is not always the case, as Pratap (2000) demonstrates in his study of shifting cultivation in Eastern India where rotation of cultivation plots can support permanent settlements. Permanence of settlement can happen with swidden cultivation if certain conditions are right such as the amount of land, fallow period, climate, soil type, vegetation cover, crop type and their demands on the soil (Jochim 1981). However, this demonstrates that a reduction in mobility is related to the type of early cultivation method and local conditions required for this system can also influence mobility. Tropical hunter-gatherers may be more likely to start cultivation on a seasonal level or continuously shifting basis and therefore permanent settlements are not necessarily needed before cultivation can begin. Non-permanence or seasonal camps are much harder to find archaeologically than permanent settlements because there will not be constant accumulation of artefacts and organic debris. This makes these types of sites more ephemeral than a fully settled site. Therefore, if the initial stages of plant cultivation occur during a more mobile phase of occupation it will be much harder to detect and this may be likely for certain parts of India.

Sedentism could also result from agricultural intensification and especially the development of more complex all year around agricultural systems, which require year round occupation. Most single season agricultural systems could be left after planting to develop on their own, even though tending may mean a better yield, and then the cultivators could return when the crop needs to be harvested. This would suit hunter-gatherers who were beginning to cultivate but still relied on wild foods for most of their diet. Therefore the issue of sedentism as a pre-requisite to plant cultivation is not clear cut and the type of cultivation system will play a key role in whether settlement is required.

2.2.2 Recognising plant cultivation and domestication

The development of plant cultivation is obviously a key element in the development of agricultural societies. In places such as the Near East this seems to be much easier to recognise due to the type of crops that are involved, major grain and pulse crops, and also because of the huge amount of detailed work that has now been conducted at archaeological sites and on the biology of the crops involved (for the plants see Zohary & Hopf 2000). This has shown that a number of crops were domesticated in this region before animals were domesticated. India is potentially a much more complicated situation because there are a large number of crops that could be indigenous and also many which are likely to have been introduced from other regions. Many of these crops are rare or hard to recognise in conventional archaeological remains such as curcurbits, yams, taro, which is due to a large extent on poor preservation. There is also a need to refine identification criteria for some more common finds in India archaeological deposits such as rice, which is hard to identify to species, and some India pulses, although Fuller (1999, 2002a, Fuller & Harvey in press) has started to resolve some of the problems. Another problem is that a lot of the wild progenitors of these crops have not been investigated in great detail and the methodology of how to distinguish accurately between wild and domestic species is not greatly developed. Also adding to this is the lack of archaeobotanical work that has been conducted in India, although it has been growing more rapidly in recent years, but there is not a vast dataset for any of the South Asian Neolithic regions as is available for the Near East. The majority of sites in India that have been analysed lack quantification for looking at assemblage change especially for weed floras therefore hindering interpretations of the early development of plant cultivation.

As already discussed above, roots and tubers may be very important in the development of agriculture in tropical regions, which may be the case for areas such as Northeast India, including Orissa, and Southeast Asia. Initial cultivation could have occurred very easily due to propagation of these crops from cuttings (Harris 1977). These crops are unfortunately very hard to find archaeologically and usually we must rely on the identification of agricultural structures such as the terraces and pondfields constructed in Polynesia (Kirch 1994). It is sometimes possible to find charred remains during flotation but these are usually rare and hard to identify. Therefore, much more work needs to be conducted on how to identify these remains and also the application of other methods such as starch grain analysis needs to be applied but this is unfortunately outside the content of this project. Hence, the available material must be investigated, which in this case is charred seeds and phytoliths.

When investigating the signs of the development of agriculture, the morphological change in the plants provides an important benchmark although this does only indicate the later stages of the process. A number of features change when a plant becomes domesticated and the most important to recognise are the loss of natural seed dispersal, the increase in seed size, and reduction or loss of seed dormancy, which is sometimes seen in the thinning of the seed coat (Harlan et al 1973, Hillman & Davies 1990a, 1990b, Harlan 1995, Smith 1995, Zohary & Hopf 2000). The toughening of the rachis in cereals or the reduction of shrinking tissue in the pods of pulses is a result of selection for the loss of natural seed dispersal (Harlan 1995). This is often regarded as the quintessential domestication trait. This feature allows more of the seeds to be collected by humans because the seeds stay on the plant where as in wild plants their seeds are freely dispersed when ripe, which is not advantageous to humans. This phenotypic change can be recognised from the plant remains found on archaeological sites and specifically the rachis or other attachments of the spikelet with cereals. In rice, the attachment of the spikelet base to the rachilla becomes toughened and a rough scar on the rachilla is a feature of domesticated types where as a smooth scar identifies wild species (Thompson 1996). However, the degree of immature harvesting must be taken into account as this will also produce a rough scar even in wild rice. This change in pulses is much harder to find because pods are not usually found and the change in the tissue of the pod would be hard to recognise in ancient material.

Studies have been conducted to try to estimate the length of time in which this development occurred, in other words how long it took wild plants that were being exploited to become domesticated therefore having the non-shattering feature (Hillman &

Davies 1990a, 1990b, Willcox 1999). This change is a process, which humans play a role in. The first phase is when the plant population has purely brittle rachises. This will continue until mutants are generated although it is likely that some non-shattering mutants are present in all large populations of wild grasses (Harlan et al. 1973). The cultivation of the plants by humans, and specifically the type of harvesting method used, will either select for or against these non-shattering mutants. Harvesting by cutting or uprooting will select more of the toughened rachis mutants and over time more and more will be incorporated in to the next generation sown the subsequent year. The rate of this change is important for questions of agricultural origins especially addressing how and why this change occurred. Wheat and barley are almost exclusively self-pollinating species and therefore under strong selection from harvesting methods could develop in to domesticates in 20 to 30 years but weak selection will be much slower (Hillman & Davies 1990a, 1990b). Lower proportions of mutants sown relative to wild growing plants, immature harvesting, or harvesting methods other than by cutting the plant will mean weak selection pressure on the population. Rice is a cross-pollinating species and shows significant out-breeding of 40-60% of fertilised florets (Oka & Morishma 1967). Fuller has suggested, using Hillman and Davies (1990a, 1990b) calculations, that with strong selection pressure domestication could occur in approximately 50 years (Fuller in press a) and it has been shown that under favourable selective conditions, including the isolation of the crop from outside influence, selection of domestic characteristics for grain stocks, and hand sowing, that domestic traits within the population will increase quickly over several generations (Oka & Morishma 1971). Over five generations, grain weight and spikelet number tended to increase as well as there being a considerable decrease in seed shedding (Oka & Morishma 1971: 357). When ideal selective conditions are not present then domestication could slow down dramatically even to more than 1000 years (Fuller in press a). Certain factors can reduce the likelihood of selection for domestic traits such as the harvesting method including paddle and basket harvesting that is common for wild cereals, re-sowing in the area of natural wild species, collection of a large enough proportion of the harvest, and the harvesting of immature grains will reduce the proportion of domestic mutants in the population. Wild rice is usually expected to be harvested when the majority of grains are immature to achieve the best recovery of grain. Basket harvesting is common with wild grasses (Jenks 1900, Harris 1984), therefore this would reduce the selective pressure making the domestication rate slower.

Increases in seed size and the reduction or loss of seed dormancy are other changes that occur during domestication. The increase in seed size is thought to be a direct influence from humans who would select for larger seeds therefore producing a greater density of plant material. Some changes in seed size probably occurred at the point of domestication in some species but the development of large seed sizes compared to the smaller wild progenitors as is clearly seen today did not occur until much later (Jupe 2003, Jupe & Fuller in prep, Fuller & Harvey in press). The loss of dormancy is reflected in the thinning of the seed coat, which allows the seeds to germinate quickly when planted. This change is the result of pressure to grow rapidly to compete for space and light in an agricultural field. There is also no need for a seed bank to be established in the soil to maintain the wild plants therefore the wild seeds with varying thicknesses in seed coats no longer exist because the seed crops (with thin seed coats) will be planted each year by humans. A good example of both of these changes can be seen in the Eastern Woodlands of North America where the independent domestication of a number of local wild plants was determined from investigations of seed size change and the thinning of the seed coats of archaeological specimens (Smith 1992, 1995). Until recently, the first agricultural remains in this part of the world were thought to be maize, which arrived from Central America in the mid to late first millennium AD (Smith 1992, 1995, Bellwood 2005). However, at a number of sites in the central interior of the Eastern Woodlands, plant remains have been found that demonstrate domestic species including summer squash (*Curcurbita pepo*), and annual forbes such as goosefoot (*Chenopodium berlandieri*), sunflower (*Helianthus annus*), and sumpweed (*Iva annua*). This appearance of domestic species begins about 4,000 B.P. (Smith 1992, 1995). At the sites of Ash and Russell Cave, large collections of goosefoot were found in storage pits sometimes as much as 50,000 seeds. These remains were found to have seed coats from 10 to 20 microns thick, which is much thinner than wild species but compares well with other domesticated *Chenopodium* species (*Chenopodium quinoa* and *Chenopodium berlandieri* subsp. *nuttalliae*) that are cultivated today in South and Central America. Maygrass, little barley, and knotweed were also found in large quantities at some sites. None of these crops are major staples in North America today and most of them are not cultivated at all, which is the result of later over-stamping by maize. At this time, the people of the Eastern woodlands were becoming increasingly sedentary. From the seventh millennium BP, there is a move to more seasonal occupation and the annual reoccupation of the same sites located in floodplains (Smith 1992:52). Therefore, the move towards sedentary life occurred prior to the initial domestication of plants in this area, although they remain seasonally mobile while cultivators, with the development of pottery and animal herding occurring even later.

2.2.3 Animal herding

Part of the whole agricultural package is the rearing of animals, which adds another dimension to subsistence systems. Animals provide an additional source of food in the form of meat, milk, and eggs, as well as having other properties useful for subsistence such as traction, manure, and hides. Herding of animals is particularly important in some early subsistence systems and may have pre-dated plant cultivation. The herding of highly mobile animals such as sheep, goat, and cattle could have fitted in well with some mobile hunter-gatherer societies. Transhumant pastoralists are suggested to be present during the first stages of development of agricultural systems in places such as Africa and South India.

In Africa, domestic animals have been suggested to appear about 9500-8840 BP in the eastern Sahara and are accompanied with incised, stamped, and impressed pottery (Marshall & Hildebrandt 2002, Bellwood 2005). Gautier (1980, 1987, 2001) and Wendorf (Close & Wendorf 1992, Wendorf et al. 1984, 2001, Wendorf & Schild 1980) have found cattle remains at Bir Kiseiba and Nabta Playa that they argue was herded, however this evidence is still controversial due to scarce morphological data. Recent morphological and genetic studies support a separate origin for cattle in Africa (Grigson 1991, 2000, Bradley et al. 1996, Bradley & Loftus 2000, Hanotte et al. 2002, Marshall & Hildebrandt 2002, Bruford et al. 2003) and some scholars have suggested a single geographic origin in the eastern Sahara (Gautier 1987, Hanotte et al. 2002). Further support comes from linguist studies that link the Northern Sudanic branch of the Nilo-Saharan family with the practise of cattle herding and pottery, with an estimate from glotto chronology of about 9000 BC (Ehret 1993, 1997, 2000, 2002, Bellwood 2005). Therefore, the other sources of supporting evidence for early cattle domestication in the eastern Sahara give more weight to the argument even if current archaeological finds are not so convincing.

With the possibility of cattle herding and pottery being early in Africa, it might be expected that plant cultivation and sedentism occurred shortly after, however, this does not seem to be the case (Marshall & Hildebrandt 2002, Barker 2003, Neuman 2004, Bellwood 2005). Plant cultivation and sedentism happened much later in Africa, although the exploitation of wild grasses, such as millets, seems to have accompanied the early herding and pottery phase. It has been suggested that cultivation may have occurred of a number of these grasses due to the appearance of microliths that could be used for sickles and grinding stones in Sudan about 5000 BC (Haaland 1999) but there is not really any over whelming evidence for cultivation rather than just harvesting. As has been suggested above for rice, all the indigenous crops of African Sahel and Savanna are annual cross pollinators and therefore would have been slow to domesticate especially if cultivated in the wild progenitors' habitats. This is reflected in the very late appearance of domestic plants of pearl millet at Tichtt in Mauretania and Birimi in northern Ghana about 1500 BC and of sorghum and African rice at about 1000 BC (Wetterstrom 1998, D'Andrea & Casey 2002). However, domestication could have occurred before this time and the lack of data at present hinders a complete insight in to this phase of African development therefore more excavation and environmental sampling of sites is needed if these dates are to be pushed back.

Parallels can be seen between the sequence of events in Africa and the evidence found in South India. The earliest pastoralism in Peninsular India is from the Ashmound culture of Neolithic South India. Evidence to reconstruct the events of the whole of South India is still lacking but a growing weight of evidence is coming from Karnataka and Andrah Pradesh. This has demonstrated sites with animal pens, mounds of burnt dung, hoof-prints, and animal bones of predominantly cattle but some sheep and goat from about 2800 BC (Allchin 1963, Korisettar et al 2001a, 2001b, Fuller 2003a, in press b). It has been suggested that there is a separate domestication of southern zebu cattle because of differences seen in rock art depictions in the area (Allchin & Allchin 1974, 1997). However, there is currently no archaeozoological evidence for this particular development and therefore the introduction of cattle from northwest India is much more plausible because sheep and goat are also introduced in to the area (Fuller in press b, Fuller 2005). At this time these people were still seasonally mobile and had pottery wares much like the early pastoralists of Africa. Again plant cultivation and sedentism came later but with not as much of a time gap in this region. Plant cultivation, which was probably initially indigenous, appears about 2300 BC with a package of two millets (*Brachiaria ramosa* and *Setaria verticillata*) and two pulses (*Vigna radiata* and *Macrotyloma uniflorum*) (Fuller 1999, 2001, 2003a, in press b, Fuller et al. 2001, 2004). Therefore, there seems to be a similar development of the transition from hunter-gatherers to farmers in parts of the African and Indian Savannahs.

2.2.4 Decoupling pottery and agriculture

Pottery is not a necessary component of early agriculture as can be seen in the sequence of development in the Near East but pottery wares are present in Mesolithic contexts in other parts of the world. In Asia and Africa, there is a very different pattern to that found in the Near East, where there is a pre-pottery Neolithic and therefore cultivation begins before pottery manufacture. Pottery has occurred in parts of Asia and Africa for a very long time (Rice 1999, Agrawal 2002, Jiarong 2002, Tsutsumi 2002, Yasuda 2002b). The earliest ceramics have been found in Yuchanyan, China dating perhaps as early as 17,000 B.P. (Jiarong 2002) and it is well known that the pottery industries in the Jomon culture of Japan were well established before agriculture began at the end of the Pleistocene (Imamura 1996). Pre-agricultural ceramics are also found in early African deposits (Close 1995, Jesse

2003) and these ceramics contain grass impressions that come from wild 'millets' although unlikely to be crops (Fuller & Smith 2004, Bellwood 2005). In India, pottery is found in Mesolithic deposits and occurs frequently in the Mesolithic sites of the Northern Vindyhas, in Uttar Pradesh. Handmade ceramics are found in the upper layers of a number of Mesolithic rock shelters and open air-sites in this area: Morahana Pahar, Baghai Khor, Lekhahia, Ghagharia and Chopani-Mando (Sharma & Misra 1980, Sharma et al. 1980a, Pal 1986). These ceramics are crude and handmade and have been dated to approximately 5,000 BC. They could represent contact with early Neolithic groups, which occur in this area at a similar time, but the ceramics are significantly different and can be suggested to represent the existence of primitive ceramic industries in the Mesolithic period of this region (Pal 1986). This development seems to have little to do with plant domestication or animal herding, which came later in this area.

It is worth considering whether the appearance of early ceramics could be another form of evidence that may suggest the early use of roots and tubers in the tropics. Pottery, as mentioned above, is found much earlier in Asia and Africa, two regions which have root and tuber agriculture. Does this early appearance of ceramics before evidence for seed cultivation demonstrate an earlier phase of root and tuber exploitation and cultivation? The majority of roots and tubers have to be processed to eliminate bitterness and toxins (Harris 1977). Pottery would be a useful commodity to assist this process but is not necessary. Piperno and Pearsall (1998: 319) suggest that ceramics may be linked to the development and spread of certain crops in the Neotropic. The development of new cooking techniques using pottery made lima and common beans a more important resource as well as the introduction of ceramic griddles, which were used to bake bitter manioc cakes and have been suggested to have quickened the development of this particular crop (Piperno & Pearsall 1998: 319) However, the use of ceramics for root and tuber processing is just one explanation for the early appearance of pottery and it has also been linked to other economic activities such as the intensified exploitation of shellfish, hunting, nut collecting, and fruit or other plant resources such as the beans suggested above (Ikawa-Smith 1976, Piperno & Pearsall 1998, Rice 1999). Rice (1999) proposes that early pottery wares could have been used for cooking, storage, or as serving containers. Much of the early pottery remains in the New World are found at sites with shellmiddens, which has lead to speculation about their uses as short-term storage or processing vessels for shellfish (Rice 1999). Pottery may make the exploitation of shellfish and molluscs less labour intensive because this activity can require substantial processing time (Osborn 1980) and therefore heating would cause the bi-valve shells to open making them easier to procure. In the southeastern United States, shellfish was suggested to have been steamed open but meat was smoked or dried and stored for later consumption, which may have been in ceramic containers (Claassen 1991). The small size of many vessels and the lack of sooting may support suggestions that early ceramics could have been used predominantly for food service rather than cooking (Ingold 1983, Rice 1999). This may not be true for India, which generally has larger open containers in the Neolithic and smaller vessels.

2.2.5 Summary of trajectories of change

What can be drawn from this review of trajectories is that areas of agricultural development can have very different sequences of this complex transition. This transformation of society can in fact have a number of different causes for each part of the sequence and the order of progression may also play a part in why and how each change happened. The best known area of plant and animal domestication, the Near East, seems to start with the development of complex sedentary (or seasonally mobile) hunter-gatherers, which then developed plant cultivation that led to domestication. This may suggest that sedentary life was related to social factors because these societies were choosing to aggregate and become less mobile. The development of plant cultivation can be seen to relate to food stress factors such as the over exploitation of wild resources or a decline in wild grasses due to climatic and environmental change because these communities were settled and therefore could not move to avoid this stress (Moore et al. 2000, Byrd 2005). Animal husbandry and the development of pottery are later developments in this area. A similar pattern seems to have occurred in the Eastern Woodlands of North America where a move towards seasonal occupation was accompanied by the start of plant cultivation and eventual domestication. Again, it has been suggested that pottery is a later development. The initial move towards agriculture in parts of Africa and South India begins with cattle herding (and perhaps sheep and goat), which allows the continuation of a more mobile existence. Pottery is also an early development in these areas. Both areas demonstrate the domestication of local flora. In South India, this occurs a few centuries after the beginning of herding but present evidence from Africa suggests this development occurred much later. Sedentism seems to be related to the development of plant domestication in both areas. The trajectories towards agricultural societies in Northern and Eastern India will be discussed in the following chapter from the available evidence and suggestions will be made as to how this might be developed with the proposed work in this project.

2.3 Identifying agricultural production systems

2.3.1 Trajectories of agricultural systems

Although, the origins of agriculture are given the most attention when examining early agricultural communities, what is mostly forgotten is the actual development of the agricultural systems and how these change over time. A recent example of work that addresses these sorts of issues is Bogaard's (2004) investigation of early agricultural systems in LBK Europe, which demonstrates the identification of a fixed plot subsistence system using the analysis of weed ecology. Changes in agricultural systems can have fundamental effects on the social interactions of communities. Knowledge of primitive cultivation systems will help to recognise them in an archaeological context.

The development of plant cultivation and the emergence of agricultural systems have predominantly been seen as an evolutionary process from primitive cultivation to complex agricultural systems. These linear transformations from hunter-gatherers to shifting cultivators to sedentary agriculturalists suggests higher levels of energy input with each subsequent level producing more nutrients per unit of land. Shifting cultivation or swidden is regarded as a primitive form of cultivation because of its mobility and the low labour input per unit of land, and this associates it with the first step from a hunter-gatherer society however as suggested above this is not always the case as has been shown in Europe (Bogaard 2004). A clear example of this uni-linear development is the work of Boserup (1965), who formed an evolutionary sequence of increasing intensification of production based on the length of the fallow period. In this model, shifting cultivation is considered primitive because it requires a lot of fallow land and less intensive labour input, which is left for many years to regenerate. Spencer and Stewart (1973) have also suggested a hierarchical list of agricultural systems starting with shifting cultivation becoming more sedentary and complex. Upland rice is generally associated with swidden and therefore mobility (White 1995). However, swidden cultivation should not necessarily be associated with mobility or labelled as a primitive form of cultivation. It is a widespread form of cropping system in the tropics, especially in forested areas, which offers an alternative agricultural system to fixed plot agriculture (Barrau 1958, 1961, Kirch 1994). It is likely that upland rice systems were developed initially from lowland *Oryza nivara* domestication and therefore a further step up the sequence from the start of rice cultivation (White 1995). It is also debateable that sedentary agriculture is more complex than some systems of shifting cultivation (Latinis 2000).

Harris has suggested that the most primitive forms of cultivation in the tropics are household gardens that later develop in to swidden plots (Harris 1973). Early agriculture in the Neotropics has also been suggested to have begun with small-scale horticulture, which then develops in to swidden cultivation (Piperno & Pearsall 1998). There is a broad spectrum of exploitation from the beginning and a growing degree of complexity and size in swidden agriculture over time. Swidden cultivation has even been suggested to have supported complex societies such as the Maya civilisation (Harris 1972). This demonstrates that swidden should not be seen as the beginning of the process of agricultural origins but as a different trajectory to fixed plot systems.

A contrast to tropical shifting cultivation is the example of temperate shifting cultivation in Neolithic Europe. As mentioned above, this was a long held view of the method of migration of a crop package across central Europe (Childe 1929, Whittle 1996a, 1996b, 1997). There is a key difference between tropical and temperate shifting cultivation that adds to the arguments against this form of subsistence system in this area and this is the difference in soil types. Tropical swidden cultivation is generally practiced on thin, rapidly leached soils that have high rainfall and are exhausted fairly quickly therefore movement of land is necessary. These soils, therefore, may not be attractive for initial experiments with plant cultivation. The temperate systems are based on much better soils and manuring was also used to enrich them (Bogaard 2004) therefore allowing the soils to be used over longer time periods. Although, it has been concluded that LBK Europe was in fact based on fixed plot agriculture rather than shifting cultivation, the study by Bogaard (2004) identifies some interesting methods for the analysis of different cultivation systems using weed ecology, which could be applied to tropical areas with sufficient ecological and archaeobotanical data.

Another implication of Bogaard's (2004) study that may apply to this thesis is the fact that these sites were always thought to be short-lived because they contained little positive evidence of settlement in terms of structures but are now thought to be occupied over a longer time period. Does this mean that sites that have shifting cultivation are even more ephemeral? If so, this implies a real challenge for identifying shifting cultivators in the tropics or recognising seasonally occupied sites from early periods.

Arboreal-based economies are another alternative to sedentary agriculture in the tropics (Latinis 2000) and have relevance to highland forested areas in Orissa, India. Arboreal resources include the exploitation of forest understory, gap, and fringe plants and animals that provide food, medicines, building materials, and other economic products. Swidden is commonly associated with arboreal-based economies but arboriculture also includes smaller scale cultivation systems such as the growing of fruit trees in the house gardens of rice farmers. These practices require a high degree of environmental management because trees have long maturation rates and therefore arboreal-based systems require long term planning and investment. There also needs to be the distinction between growing tree crops that are staples such as breadfruit and minor crops such as mangos and tamarind. In India, tree crops are generally of minor importance, which supplement other types of agriculture.

Arboreal-based economies are still poorly understood but may have played a significant role in past subsistence economies. Many parts of island Southeast Asia are forested and presently contain many such subsistence systems. Muluku, in eastern Indonesia, contains mountainous tropical forest, and provides ethnographic evidence of an arboreal-based subsistence system. Traditional Mulukan subsistence can be divided in to two systems: arboreal and coastal marine based. Resources within the arboreal subsistence system are categorised into long term and short term classes. Long term practices are predominant and short term garden plots are cultivated but are later turned into long term plots. Three aspects of this model are important for archaeological investigations of forested areas. Firstly, this study suggests that the Malukan arboreal-based system would be invisible in the archaeological record prior to the introduction of exotic New World species. This is the result of the use of slash and rot rather than slash and burn. In addition to the likely lack of charred remains, any pollen or seed remains that did survive would appear much like the natural environment. This type of subsistence system is a manipulation of the natural environment and therefore may not be altered enough to be visible archaeologically. Secondly, conventional categories of hunter-gatherers and farmers may not apply to this particular type of subsistence (Latinis 2000). Gosden (1995) suggests that we need to reject these pre-existing categories to fully appreciate the richness and variety of the subsistence economies of forested tropical areas. Thirdly, the Malukan arboreal-based subsistence system has superiority in this particular environment. The Malukan villages have neighbouring wet-rice farmers, who have adopted aspects of the arboreal-based system but the Malukans have resisted adopting the rice agriculture. This results from the arboreal-based system containing more food choices and having a higher calorie intake than found in wet-rice farming. This may well have implications for other areas where introduced agricultural systems have not been adopted by the indigenous population and may have resulted in the persistence of traditional arboreal-based economies to the present day.

Another alternative trajectory to the uni-linear development of agricultural systems is the seasonally flooded rice cultivation model (White 1995). This refers to fixed field systems not shifting systems. This model is based on the assumption that the initial steps towards rice cultivation and domestication must have taken place in the habitat of the wild progenitor. This model is appropriate to explain the domestication of *Oryza nivara* but not *Oryza rufipogon*. Early cultivation happened in fixed plots that were seasonally inundated with water such as the edges of lakes and rivers. More labour intensive wetland rice cultivation and upland shifting cultivation systems are developed later. This is seen as a shift from opportunistic cultivation to systematic, integrated, and focused cultivation. A similar model has been suggested by Sherratt (1980) for the Near East. He proposed that these seasonally flooded areas would have had prolonged productivity because there is no need for water control, minor forest clearance, and the fertility is replaced through run off. With these models mobility is not an issue because these fixed plots could be exploited whether the cultivators were seasonally mobile or sedentary.

White's (1995) rice model has implications for the beginning of rice cultivation in India. Early farming sites in the Belan River Valley are situated close to the banks of the river much like the sites from Thailand discussed in her model. At Mahagara, there are areas close to the site, which would have seasonally flooded and could have been used in the manner outlined by White (1995). These areas would have contained wild rice that could have been manipulated for greater yields. However, if this was the case, then domestication would have been a slow process with the amount of out-breeding that would have taken place using the natural habitat of wild rice as has been suggested above. This means that low selection pressure was likely for rice domestication in this environment.

This does not rule out this model because the early cultivators were not aiming to domesticate the rice, as they had no knowledge of this at the time, all they would have been aiming for is to secure their harvests and also produce greater yields. The process of sowing seeds would have been enough to do this and any effect on the plant produced by certain harvesting methods would have been unconscious and non-domesticate harvesting methods such as basket harvesting may have been efficient. This may have promoted a shift towards river edge settlements and increases in the degree of sedentism.

The uni-linear approach to agricultural origins and changes in agricultural systems needs to be rethought for tropical regions. Many different systems of exploitation, cultivation, and agriculture exist in tropical regions and it is therefore not a simple process. Shifting cultivation and arboreal-based economies can be complex and are able to support sedentary societies or be utilised by seasonally mobile groups. Some of these primitive forms of agriculture may be hard to recognise archaeologically because they resemble the natural habitats of the area such as with arboreal systems and also if wetland rice cultivation is occurring in the natural environment of the wild progenitor. All of these different subsistence systems need to be investigated in greater detail to produce a fuller insight in to the spectrum of trajectories towards agriculture in the tropics as well as other world regions.

2.3.2 Identifying social changes

Currently, there are very few studies that attempt to recognise changes in the social complexity of early agricultural societies, even in the large amount of literature written on the Near East (Byrd 1994, 2005, Bar-Yosef & Meadow 1995, Hayden 1995b, Watson 1995, Kuijt 2000a, 2000b). Kuijt (2000b) suggests that more attention should be paid to how changes in the scale of communities and the nature of civic leadership and social complexity reflect how Neolithic peoples created new ways of living with the recent innovation of food production systems. The development or intensification of agricultural systems creates changes in the organisation of society. Increasingly complex systems of subsistence require more focus on the organisation of labour whether this is at a household or community level. Obviously, the larger a community gets, or the increased need for surpluses for trade or storage, then the more food it has to produce, which might provoke a number of different economic reactions. Changes to food processing techniques (Wright 1994, 2000), more community based agriculture, or the need to employ more labour than exists within the household (Stone et al. 1990), and the intensification or the extension of the existing agricultural system may all be developments due to an increased need for food stuffs.

The recognition of these changes in archaeological assemblages has been approached in a number of ways. Wright (1994) has suggested that the intensification of use of foodstuffs is the result of more intensified processing methods that exposes more starch for digestion. This has been demonstrated by changes in the types and numbers of ground-stone tools used in the Near East from the Upper Palaeolithic to the Pottery Neolithic. Two episodes of intensification have been suggested, one coinciding with the move towards sedentism and the other with the onset of farming. There is a trend towards increasing numbers of grinding tools, which were used to maximise the value of plant foods from limited areas and also the same harvest could support increasing numbers of people in the settlements. This is an interesting way of addressing the question of agricultural intensification and applies to wild foods as well as domesticated ones.

Changes in architecture and the size of settlements may demonstrate population aggregation as a result of a need for the centralization of labour and the development of regional economic and ritual centres. Kuijt (2000b) suggests that the abandonment of large villages of the late pre-pottery Neolithic B in the Jordanian Highlands was the result of the inability to develop new means of organising leadership in the face of rapid economic and environmental changes. This transition to small pottery Neolithic villages of less than one hundred people demonstrates the process of decentralisation of the society. Such patterns of architectural and settlement change need to be investigated in the regions under study in this project and compared to the archaeobotanical data, which may give greater insight into the social changes that accompanied any economic changes in these communities.

Archaeobotanical assemblages can also be used to understand social organisation including the deployment and scheduling of labour throughout the year. Fuller and colleagues have used macro-botanical remains (Fuller et al. in press, Stevens 2003, in press) as well as phytolith analysis (Harvey & Fuller 2005) to demonstrate differences in social organisation on a number of sites. This form of social archaeobotany suggests that the content of the archaeobotanical assemblage is much more informative than the context. There are two types of context: Hodder's (1991) 'contextual archaeology' is where an artefact or site is seen in relation to its social setting, specific to a known time and place, where as an archaeological context refers to the specific type of deposits in which the finds are found. Archaeobotanists use the second type of context as a starting point for interpreting human activities; however the majority of archaeobotanical assemblages are not related to their depositional environments. Most samples are in fact from secondary or tertiary deposits and therefore using the context would be misleading for these particular assemblages. This was recognised implicitly by Hillman in his 1973 paper. Fuller et al. (in press) go further by suggesting these re-deposited materials reflect average and recurrent patterns of activity. Therefore, the examination of the content of these deposits can be used to infer crop processing stages and lead to interpretations of social organisation. Key to these social interpretations is the stage at which the crop is stored because this has relevance to the organisation of labour (Stevens 2003). There are three choices for initial processing of the grain: storage of the whole panicle and straw; storage in spikelet form; storage as cleaned grain. This implies an increasingly large seasonal workforce for initial processing and decreasing daily processing on the site. These different choices of labour will effect what is found in the archaeobotanical assemblages.

Traditionally, macro-botanical remains are used for the interpretations of crop processing stages but there are problems with the preservational biases associated with the need for charring for the survival of the assemblage. This can be overcome by the use of phytolith analysis (Harvey & Fuller 2005) and this is discussed further in chapter five as it relates directly to the methodological approaches employed in this project.

2.4 Summary

There still seem to be many issues unresolved in terms of the development of agriculture and the spread of crop plants and this is particularly the case with India. Much work has been concerned with the questions of what, when, and where agriculture began and less work on the harder questions of how and why these processes occurred has taken place. Many theories concerned with agricultural origins developed when there was a limited archaeological dataset and this led to general models. Most theories are concerned with a central factor such as population growth, environmental or climatic change, biological, and social issues. This approach oversimplifies this complex transition because the development of agriculture, whether indigenous or introduced, should be seen as a mosaic of many processes, which are all interacting to form a unique trajectory towards a new subsistence strategy. Each region's development should be investigated separately, although interaction and influences with other areas should also be considered. India is a good example of how complex this transition can potentially be as from present evidence there seems to be many areas that developed individual agricultural systems. The unique nature of this development is influenced by the local climate and environment, and consequently the plants and animals located within it, which could potentially be domesticated. Plant cultivation is only one of the developments of agricultural communities. Sedentism, pottery, and animal herding are also important related developments and the order in which these occur and how they happen seem to be different in the various world regions. As well as investigating agricultural development, the actual agricultural system used, further changes and developments of this system, and the implications this had on how the society organises itself is another aspect, which needs attention in this project. This can be investigated in a number of ways but in this project the archaeobotanical assemblage will be used to try and give a more social insight in to the development of agricultural subsistence in the Neolithic and Chalcolithic communities of Northern and Eastern India. This is to determine the basis of subsistence and its social organisation.

2.4.1 Key issues to consider for Northern and Eastern India

- This area lacks a large database therefore drawing together current evidence with the new data from this project can start to address the questions of what, when, and where agricultural developments occurred.
- With all of this evidence, an idea of the trajectory towards agriculture can be formulated allowing a greater insight in to the questions of why and how these changes might have happened.
- A quantitative analysis of the data in this project can start to address the complex questions of agricultural development on a different level than most other studies in India. This will enable investigations in to the agricultural systems and their social organisation.

Chapter 3

Geographical background to study areas

In this chapter the modern geographic setting is introduced including the population, physical features, geology, soils, climatic regimes, and vegetations patterns. Modern agriculture is discussed for the two study regions as well as an overview of the likely indigenous and introduced crops that may be encountered during the archaeobotanical analysis. Current evidence for palaeoclimate and landscape changes in antiquity are discussed. The last part of the chapter looks at tribal groups within India today, particularly those that still populate Orissa, who use different modes of subsistence including hunting and gathering and traditional forms of agriculture. This focuses on their subsistence regimes and their exploitation of natural resources versus agricultural production.

3.1 Population

Today India has a population of over 1 billion. Religion is a very important part of Indian society with the largest two religious groups being Hindus (82%) and Muslims (11%). Other religious groups include Christians, Buddhists, Sikhs, Jains, and Parsis but these are in relatively small numbers compared to the other two groups. Hinduism, which includes many sects, deities, and variants, dominates Indian culture and this is reflected in the system of hereditary castes, which makes up Indian society today (Robinson 1989). This emphasizes hereditary social differences and promotes inequality between groups in society. There is still a predominantly rural population in India with 75% of people living in the countryside but all control of the country comes from within the cities most of which are located on the Indo-Gangetic Plain.

India is also made up of regional and tribal groupings and this is reflected in the huge number of languages, which are spoken in the country. There are 18 official languages and more than one thousand dialects. Generally, Indo-European languages are spoken in the north and Dravidian languages in the south. Hindi is the national language although not always spoken and English is spoken throughout the country, especially by the well educated classes, a legacy of colonial times. In Uttar Pradesh, Hindi is the dominant language. In Orissa, Oriya is the state language although there are many tribal languages also spoken. Munda languages are spoken in Southern Orissa and parts of adjacent states. These are related to the Austro-Asiatic language family of Southeast Asia and the spread of this language through Orissa has been suggested to relate to a certain subsistence pattern such as upland shifting cultivation (Fuller in press b). Most authors have assumed a Neolithic immigration from Southeast Asia (Glover & Higham 1996, Bellwood 2005, Fuller 2003a) although recently a case has been made for migration from India (Fuller in press b).

3.2 Physical features, geology, and soils

India is the seventh largest country in the world and dominates the South Asian sub-continent. For a political map with physical features see figure 3.1. The land mass it occupies is 32,87,782 sq km (Qazi 2000). India is 12 times the size of the United Kingdom. It is situated solely in the northern hemisphere between 8° 4' and 37°6' North latitude and 68°7' and 97°25' East longitudes. The land frontier in the north covers 15, 200 km and the coastline is 7516.5 km long. India stretches from the Himalayas in the North to Cape Comorin in the South. It lies between Afghanistan, and Pakistan on its western border and Bangledesh, and Burma on the eastern borders with Southeast Asia further to the east (fig. 3.1). The Himalaya forms a natural boundary with Nepal and China to the North of India, and together with the hills of Pakistan and the hills of Northeast Assam and Burma, clearly demarcates the Indian subcontinent.

The Indian landmass can be divided into three distinct areas: the Himalayas and its associated mountain ranges to the west and east marking the Northern boundary of the Indian subcontinent; the Indo-Gangetic Alluvial plain from the Indus delta to Assam; and the Peninsula, which is the area south of the Indo-Gangetic plain composed largely of archean granites, gneisses, and the Deccan basalts.

The Himalayas dominate the northern borders of India. This mountain system is approximately 160 km wide and 2400 km long. The Himalayas can be divided in to three parallel ranges; i) Greater Himalayas, ii) Lesser Himalayas, and iii) outer Himalayas. The Himalayas are the youngest and highest mountains of the world. They did not come into existence until approximately 65-70 million years ago but the mountains major period of upheaval started in the late Cretaceous and continued on through to the Lower Pleistocene. During the last 20,000 years, the Himalayas have risen approximately 2,000 metres (Mathur 2003).

Tertiary metamorphic rocks make up the central part of the Himalayas and they were created as a result of the crumpling and fissuring process of the Indian plate moving underneath the Asian Plate (Robinson 1989). For a geological map of India see figure 3.2. The rest of the range contains older rock formations and all major periods are represented throughout the range. The highest peaks are in the Greater Himalayas: Mount Everest (29,141 ft), and Kanchanjanga (27,815 ft). This great height has economic importance as it acts as a climatic barrier for the monsoons and also prevents cold northerly winds from entering the country (Qazi 2000).

South of the Himalayas is the Indo-Gangetic plain, which is between 200-300 km wide and about 2400 km long. It originated in the Eocene period, 40 million years ago. This area is formed of deep alluvial deposits ranging in depth from 100m to over 5000m (see figure 3.3 for a soil map of India). Massive beds of clay, silt, and sand make up today's rivers in this region. The oldest alluvial deposits, dating to the middle Pleistocene, are found from West Bengal to Uttar Pradesh. The alluvial deposits have been deposited in a large part by the River Ganga, the most important river in India. The Ganga originates in the Himalaya at a height of 6000 m in the Gangotri glacier from a little ice in cave Gomukh (Hajra et al. 1996) and is also fed by many other tributaries that come down from the Himalayas. It flows in a westerly direction for the first 30 km then sweeps southwards. It forms the largest alluvial plain in the world. The land is generally flat but tilts slightly eastwards. From the Yamuna River in the west to the Bay of Bengal in the east there is a drop of 700 ft. The Indo-Gangetic plain has the most economically important agricultural soils in South Asia. The alluvial silts are high in nutrients and therefore very fertile. As a result this is one of the most densely populated areas in the world and most of India's largest cities are concentrated on the plain. The Belan River valley, in which some of the sites investigated on this project are located, is part of this fertile Indo-Gangetic plain and lies in the Vindyhan plateau which occupies part of the trans-Yamuna tract of Uttar Pradesh (Joshi 1968).

The Peninsula is made up of the Deccan Plateau and Coastal plains. It lies to the South of the Indo-Gangetic plain and is separated from it by a number of hill ranges; the Vindhyas, Satpura, Mahadeo, Maikal and Sarguja (Qazi 2000). The Peninsula tilts eastwards meaning that the majority of rivers drain in to the eastern coastal plains. In the north Deccan, the chief rivers are Chambal, Son, Parvati, Damodar, Ken, and Betwa, which all drain in to the Ganga River. Most of the other major rivers (Mahanadi, which is Orissa's largest River, Godavari, Krishna, and Cauvery) drain in to the Bay of Bengal, while a couple of Rivers (Tapti, Narmada) flow westwards and drench the northern peninsula. The state of Orissa, which is the other area of study, is situated on the eastern coast of Peninsular India with the states of West Bengal and Bihar to the north and Andhra Pradesh to the south.

The Archean rocks, which comprise a large part of the Peninsula, are some of the oldest in the world. High grade gneissic rocks are found in five regions; the oldest of these (charnockites and khondalites) are found in southern and eastern India and date to 3100 million years ago. Gneisses are also found in the Eastern Ghats, Rajasthan, the Aravalli-Dehli belt, and Bihar and Orissa in the north-eastern part of the Peninsula. Red soils have developed from this Archaean bedrock and cover most of the Peninsula area (Spate 1957). They are light sandy to gravely soils and can be easily worked but do not retain water. Red soils can be cultivated easily and provide the majority of matrix for the cultivation of rice, millets, potatoes, and fruits in Orissa (Missal 1994). These are different from laterites, which are also present but only in limited areas and many of these are under the highest rainfall regimes. Laterites can be extremely acidic and lack lime and organic matter. Therefore, these soils are not always good agricultural soils and are more likely to be exploited as building material in this area. In Orissa, laterites are largely found capping hills and plateaus and can be to a considerable thickness. Large areas of Khurda district are made up of laterites. Rice can be grown on these soils, as in this area, they are rich in nutrients (Hajra et al. 1996). Overlying the Archaean base are ancient sedimentary rocks. The oldest of these is the Vindhyan series dating to the pre-Cambrian period. These consist of sandstones, shales, and limestones. These beds stretch from Bihar in the east to the Aravallis in the west. Post-Cambrian deposits consist of a Gondwana series of sedimentary rocks and are concentrated in three main areas: the Damodar valley of West Bengal, an outcrop in Madhya Pradesh along the Mahanadi River, and a series along the Godavari from Nagpur to the delta. These are very important economically because they contain the majority of India's coal resources. Cretaceous lava flows of the Deccan trap are the most recent geological formation on the peninsula and form clay-rich black 'cotton' soils. As the name indicates these are best suited to cotton cultivation and can be found in the southern districts of Orissa, the Bundelkhand region of Uttar Pradesh, and to the south in Maharashtra. These soils are rich in nitrogen and organic matter. Orissa also contains more recent alluvial soils in the coastal and deltaic regions, which are highly productive agricultural soils predominantly used for rice paddy. Orissa's coast is made up of sand and sand dunes alternating with deltaic swamps (Hajra et al. 1996). Some of these coastal tracts are formed of peats. An area of cultivated alluvial and lateritic formations lies behind the coastal belt.

The state of Orissa has very diverse physical features. There is a series of broken mountain systems, which is a continuous range of hills broken by the Mahanadi valley (Swaminathan & Ellis 1996). High peaks in this range are Mahendragiri (1501m) and Meghasini (1250m). The Eastern Ghats extend over southern districts of the state and constitutes 36% of the total area of the state. The hill ranges of the Eastern Ghats have extensive plateaus at elevations of 300m and 450m. The chief river of the region is the Mahanadi River, which is the fourth largest basin in India. The Rivers source is in the Maikal Hills in Madhya Pradesh and flows east through the Eastern Ghats and enters the Bay of Bengal east of Cuttack, forming a huge delta in Orissa. Another geographic feature in Orissa is Chilka Lake. It is the largest salt water lake in India being 64 kms in length and 80kms in width. Chilka Lake was formed by the deposition of sand away from the shore, which cut off a portion of the sea to form a saline lake. It is connected to the Bay of Bengal and receives flood water from the River Daya and other rivulets.

3.3 Climate and vegetation

Even though India is a tropical region, the climate varies considerably. The Rajasthan desert, being the driest and hottest, is situated in the north-west and much wetter areas are found in the north-east of the country. The climate of the Indian sub-continent is dominated by two monsoon systems (Robinson 1989). The north-east (or winter) monsoon, originating from high pressure build up in Central Asia, is generally weak and only affects north-western parts of India and the Southeast Peninsula. The more significant southwest monsoon (summer monsoon) determines the pattern of rainfall over the whole of India between 1st of June and the middle of October and provides 90 % of the annual rainfall. For a map of the rainfall during the monsoon see figure 3.4. The date of onset is earlier in Calcutta than in Delhi. Most of all the major Rivers are fed by the monsoons, both winter and summer, and floods often occur in the Indus, Ganges, and Peninsular rivers. Agriculture is reliant on both monsoons and therefore if the rains are late or fail altogether it has dire affects on economic output.

The Belan River valley is situated in Allahabad district of Uttar Pradesh. This district is characterised by a long and hot summer from March to June (Joshi 1968). The highest temperatures are reached in May when the mean daily maximum is 41.8°C. This is followed by the on-set of the southwest monsoon in June. Temperatures drop, humidity rises, and rainfall increases considerably. Eighty eight per cent of the rainfall is concentrated in July and August and the normal annual rainfall is 975.4mm. A map of the annual rainfall for India can be seen in figure 3.5. From mid-November through to February, temperatures are at their lowest with January being the coldest month (daily maximum 23.7°C). Temperatures can, however, reach as little as 1.1°C.

These climatic conditions support the growth of dry deciduous and xerophytic forests. For a map of the vegetation found in India see figure 3.6. Tropical dry deciduous forest used to be widespread and would have covered the majority of Allahabad district but it is now restricted to the trans-Yumana area because of agricultural development of the fertile alluvial soils (Pal 2002). The forests have now degraded to open scrub jungles with scattered small trees like *Butea monosperma* (a dry deciduous tree), *Streblus asper*, *Casearia tomentosa*, *Holarrhena antidysenterica*, *Mallotus philippensis* and thorny species such as *Ziziphus*, *Acacia*, and *Mimosa* (Roy 1996). Dense forests are very restricted in the Indo-Gangetic Plain and can be found in the Terai regions of the Himalayas and areas bordering Bundelkhand, Vindhya, and Kaimur Hills. Further east of Uttar Pradesh in Bihar, more forested areas can be found and in West Bengal tropical evergreen forests and mangroves are found. *Shorea robusta*, *Tectona grandis*, *Madhuca latifolia*, *Mangifera indica*, *Dalbergia sissoo* are all very important economic plants and are found in the moister variants of dry deciduous or moist deciduous vegetation. Groves of mango and guava are found in the Allahabad area. This may indicate that aboriculture replaced the indigenous forest in this area.

In the Indo-Gangetic plain there are five types of forests: i) Sal forest, ii) Mixed forests, iii) Swamp forest, iv) Alluvial forests, v) Mangroves of Sunderbans (Roy 1996). Sal forest is dominated by Sal (*Shorea robusta*), which makes up 90% of this type of forest. It grows best in well-drained loamy soils, found mostly on slopes. Sal forest is found predominantly in North Kheri, which is in northern Uttar Pradesh. This is probably the late Holocene composition and likely to be the result of human action. It must also be pointed out that there is an equifinality problem with thorny scrub vegetation that could result from lower rainfall or human impact.

The Mixed forests are characterised by a large number of species and these vary depending on local factors. Common species include *Bombax officinalis*, *Lagerstroemia parviflora*, *Stereospernum suaveolens*, *Emblica offcinalis*, *Adina cordifolia*, etc (Roy 1996:

222). In drier conditions, thorny species are also present such as species of *Ziziphus* and *Acacia*. In the Vindyhan region, dry mixed deciduous forest and dry thorny forests are the dominating forest types. Mixed deciduous forest includes *Terminalia tomentosa*, *Anogeissus latifolia*, *Cordia myxa*, *Acacia catechu*, *Ficus tomentosa*, *Albizia lebbeck*. *Dendrocalamus strictus* is the common bamboo and *Tectona grandis* can occur on quartzites and gneiss in Jhansi district. Moisture loving species will occur next to perennial streams and in moist ravines such as *Terminalia arjuna*, *Syzygium cumini*, *Ficus glomerata*, etc. Dry thorny forests occur in dry, usually level, ground. This scrub vegetation includes *Ziziphus* spp., *Acacia leucophloea*, *Butea monosperma*, *Capparis aphylla* etc.

Swamp forests occur in water-logged areas and they are characterised by water-loving species such as *Syzygium cumini*, *Trewia nudiflora*, *Ficus glomerata*, *Terminalia arjuna*, *Celtis tetrandra*, and *Albizia procera* etc (Roy 1996). At the edges of streams, it includes the trees *Barringtonia acutangula* and *Salix tetrasperma*. Alluvial forests are formed on alluvium deposited on the banks of rivers and are dominated by *Tamarix dioica*, *Saccharum spontaneum*, and *Saccharum munga*. When the alluvium ceases to be deposited then the forest will be invaded by savannah trees such as *Acacia catechu*, *Dalbergia sissoo*, *Ziziphus mauritiana*.

Mangrove forests are permanently wet with tidal salt water. These are restricted in the Indo-Gangetic plain to the Sunderbans of West Bengal (Roy 1996). They consist of distinctive species such as *Heritiera fomes*, *Rhizophora* spp., *Kandelia candel*, *Avicennia alba*, *Bruguiera conjugate*.

Orissa follows the same general pattern of climate as Uttar Pradesh but is significantly wetter and there are more variations in temperature due to changes in altitude. Summer (March to June) has high temperatures, ranging from 27°C to 49°C, and occasional rains

(Dash 1997). The monsoon period starts in July and lasts until October. The average rainfall is 1600mm per annum and 80% of this falls in this period. Orissa suffers devastating floods each year due to the monsoon rains, which causes the Mahanadi River to break its banks. After the monsoon rains have subsided, lower temperatures ensue from November through to February ranging from 4.4°C to 15.6°C.

Orissa's geographical position, its wide range of physical features, and climatic conditions creates an extremely diverse flora. This gives the state a vast economic potential (Missal 1994). The hilly forests, high peaks, long coastline, large riverine system, brackish waters, and coastal plains construct a wide range of ecological habitats and therefore a broad spectrum of vegetation. The substantial monsoon in Orissa prevents there being any deserts or semi-arid areas in the state but anthropogenic degradation can still lead to scrub vegetation. The forested areas of Orissa have been declining in recent years due to agricultural exploitation and from 1990 to 1993 the coverage is reported to have reduced from 35.4% to 16.9% in the state (Sinha 1999). The district of Phulbani in the west of Orissa has the greatest coverage of forest being 53.7% of the vegetation. An interesting aspect of the forest vegetation in Orissa is the overlapping of southern and northern types of forests in the Koraput District (Swaminathan & Ellis 1996). This means that the Sal forest of the north merges with the Teak forest from more southern parts. This is the result of the difference in climatic and edaphic factors preferred by Teak and Sal. Sal generally requires wetter (1200 to 2000 mm) and slightly colder climates (10°C to 20°C). Teak survives in warmer (16°C to 25°C) and drier areas (min annual rainfall = 750mm and max same as for sal). They also have different soil preferences. Sal grows on acidic iron rich soils and can be found on laterite. Teak is found on alluvial, iron rich, and black soils, which are well-drained (Meher-Homji 2001).

There are six types of forest in Orissa (Swaminathan & Ellis 1996, Verma 1996): i) Northern tropical moist deciduous forest, ii) Tropical semi-evergreen forest, iii) Southern tropical dry deciduous forest, iv) Dry savannah forest, v) Montane subtropical forest, vi) Scrub forest.

Northern tropical deciduous forest consists of two types, Sal forest and then the rest. Sal forests are dominated by *Shorea robusta* usually forming 60 to 90 % of the top canopy. These forests are found mostly in the northern and central parts of Orissa. The composition of the forest depends on the rainfall and humidity of the specific area. Sal prefers moist, moderately heavy but well drained soils (Meher-Homji 1971). Under dry conditions, northern and eastern aspects are favourable. Sal trees occur on level ground, in valleys, and on the slopes of hills. Shifting cultivation has disturbed this type of natural vegetation and has resulted in its replacement by scrub forest, bamboo, or grasslands where extreme degradation has taken place but Sal generally does well under human disturbance such as long fallow and coppicing. Parlakimedi on the southern border of Orissa with Andhra Pradesh seems to be the southern most extent of Sal. Some of the trees that Sal can be seen in association with are *Albizia procera*, *Anogeissus latifolia*, *Diospyros melanoxylon*, *Madhuca longifolia*, and *Terminalia alata*. In coastal Sal forests, *Aphanamixis polystachya*, *Elaeocarpus robusta*, *E. tectorius* are present as well as *Amomum dealbatum* because of the rich ground. The large bamboos, *Bambusa arundinacea* and *Dendrocalamus strictus*, can also be found in coastal forests.

Meher-Homji (2001) has separated the Sal forests of Orissa in to five different vegetation types depending on changes in soils, rainfall, and altitude in this area. All the forest types are dominated by Sal (*Shorea robusta*). *Shorea-Buchanania-Cleistanthus* (dry deciduous Sal) vegetation type occurs in Dhenkanal, Sambalpur, Bolangir, Kalahandi, and Baudh-Khondmal districts of Orissa. These areas have an annual rainfall of 1400-2000 mm.

The second vegetation type is *Shorea-Cleistanthus-Croton* (dry deciduous) and is not much different from the first type but occurs in slightly drier areas and at altitudes of 100m to 400m. This vegetation type can be found in Balasore and Keonjhar districts of Orissa. *Shorea-Terminalia-Adina* (intermediate between dry and moist Sal forest) vegetation type is found mostly in Southern Orissa. Shifting cultivation that is conducted in this forest usually produces *Cajanus cajan* (Pigeon pea) and *Curcuma longa* (turmeric) as well as rice. In Puri and Cuttuck districts, moist deciduous forest is dominant (*Shorea-Dillenia-Pterospermum* type). The fifth type of Sal forest is *Shorea-Syzygium operculatum-Toona-Symplocos* type (an evergreen forest) and occurs in plateaux and hill regions of Bihar and Orissa such as the Similipal massif and the Keonjhar plateau. This type of forest is described below.

Tropical semi evergreen forests are moist deciduous forest mixed with some evergreen elements. These forests can be found in Simplipal National Tiger Park of Mayurbhanj district, and in Keonjhar, Puri, Ganjam and Koraput districts. Characteristic large trees are *Artocarpus lakoocha*, *Bridelia tomentosa*, *Dillenia pentagyna*, *Firmiana colorata*, *Mangerifera indica* (fruit), *Michelia champaca*, and *Xylia xylocarpa*. Some of the smaller trees present are *Aphanamixis polystachya*, *Mesua nagassarium* and *Phoebe lanceolata*.

The Southern tropical dry deciduous forest is the most common type of forest along the Eastern Ghats (Swaminathan & Ellis 1996: 484). Trees that are commonly encountered are *Buchanania lanzan*, *Cassia fistula*, *Gardenia gummifera*, *Hardwickia binata*, *Madhuca longifolia*, *Tectona grandis*, *Terminalia alata*, *T. cuneata*, *T. bellirica* and *T. chebula*. The lower canopy is entirely deciduous. Bamboos (*Dendrocalamus strictus*) grow well in these forests but canes and palms are absent.

Dry savannah forests are the result of biotic factors such as burning and grazing. They are seen mostly on hill tops and common trees include *Phyllanthus emblica*, *Pterocarpus marsupium* and *Terminalia chebula* mixed with *Phoenix humilis* var. *pedunculata* (source of fruit). This type of forest only occurs very rarely in Orissa.

Scrub forest is a result of degraded dry deciduous forest and is usually found at bases of hills and on the borders of villages. Bamboos are present and the scrub is often thorny, predominantly made up of *Acacia* and *Ziziphus* species.

Bamboo formations oust Sal and Terminalia in many of the valleys and eastern plains. Thorny bamboo (*Bambusa arundinacea*) is prevalent in these areas where as *Dendrocalamus strictus* occupies hills and some areas of the Central tract (Haines 1925).

As mentioned above, the coastal tracts of alluvium are dedicated to agriculture particularly rice paddies. The forest date (*Phoenix sylvestris*) and the toddy palm (*Borassus flabelliformis*) are present in more sandy areas and also *Coco nucifera* nearer the sea (Haines 1925). Mangrove formations are also present in Orissa from the Baitarani River to south of the Mahanadi River. Saline marshes are present in Balasore and other places in Orissa having characteristic species such as *Exoecaria agallocha* and *Acanthus ilicifolius* (Haines 1925).

3.4 Modern agriculture in India

Agriculture plays a significant role in the economy of modern day India. Approximately one-third of India's gross national product comes from agricultural production. Rice is the dominant crop of India, producing between 1980 and 1984, 54.6 million metric tonnes of grain (Robinson 1989). On average 160.7 million hectares are cultivated per year and 25% of this is rice. Today in India, each person consumes 1.5kg of rice per day. Wheat is the next highly produced crop covering 15% of the cropped area. Other crops exploited in India are a large variety of millets and pulses, maize, roots and tubers, sugar cane, groundnut, cotton, jute, coffee, tea, tobacco and rubber. Fruit crops are also an important part of Indian cultivation systems especially mangos, coconuts, and jackfruit.

The scheduling of crops is determined by the wet and dry seasons. There are two main types of crops: kharif or monsoon crops, which are sown after the onset of the rains in June or July and harvested during the autumn; and rabi crops, which are sown after the rainy season and harvested in the spring. Typical kharif crops are rice, sorghum, cotton, sesame, and some small millets. Wheat, barley, linseed, gram, rapeseed and mustard are all used as rabi crops but none of the mentioned crops are exclusively kharif or rabi crops and if conditions are favourable can be produced in either season. For example, different varieties of rice can be used to produce four crops per year in some parts of India.

Agriculture dominates the economy of Uttar Pradesh and 76% of the people rely on it for work. Wheat is the most important crop in the state and Uttar Pradesh has 33% of the total cultivated area of wheat within India (Tiwari 1971). It is predominantly grown in the Ganga Yamuna tract and is an autumn sown crop relying on the alluvium of the Ganges Plain and the cool winter climate. Rice is the next most important crop and is the staple diet of the eastern districts of Uttar Pradesh. The yield of rice per acre is low compared to other states although the state has about 20 % of the total cultivated area of rice in India. Other important crops are maize, barley, pearl millet, and chickpea. Pulses make up about 20 % of the cultivated area within Uttar Pradesh. Sesame and groundnut are the most important oil crops each covering about 1% of the total cultivated area in the state. Cotton is not a highly produced crop within Uttar Pradesh and needs irrigation in most areas. It is better suited to the black cotton soils of central India. Sugarcane is an important cash crop and Uttar Pradesh produces a large amount of India's total yield (46%). It is well suited to the loam and clay loam alluvium found throughout the state and grows best in regions with 750 to 1200 mm of rainfall. Most of the production is in un-irrigated fields within the state therefore relying on rainfall and particularly the monsoon period flooding of the rivers.

Orissa follows this general pattern of crop production with rice being its dominant crop (Sinha 1999). This is predominantly wetland rice grown on the alluvial deposits left by the huge riverine system that traverses the state. Finger millet is the second most important crop in Orissa. Maize is the next highly produced and then wheat. Other millets and a number of pulses are also produced in many areas. Oil seeds such as groundnut, sesame and mustard (*Brassica juncea*) are produced. Sugarcane is an important cash crop as well as potato and jute. In the more hilly areas of the state, forest products are exploited and shifting agriculture is still practised in some areas by the tribal groups, which is discussed in more detail below. Primitive methods are employed such as 'slash and burn', called *Jhum* or, in Orissa, *podu* cultivation. This practise relies heavily on the rains as irrigation is hard to employ on hill slopes and is therefore not even attempted in the majority of cases (Patnaik 1997). This type of agriculture causes substantial damage to the forest and has therefore been discouraged in recent years. Hence, tribal groups are turning to a combination of forest and wetland cultivation or relying only on wetland regimes.

3.5 Ancient crops and crop origins

There are a large number of crops which may have been exploited by the early farming communities in the Indo-Gangetic plain and Eastern parts of Peninsular India (see figures 1.2 and 1.3). It is becoming clear that some of these crops are indigenous to India and this may even have occurred in the regions under investigation here. However, to grasp the whole picture of early agricultural production, crops could also have come from other countries and become adopted by the early people in the given areas because they fitted in to an existing agricultural system allowing the intensification or extension of existing production, and in some cases, gradually have replaced or 'overstamped' the existing plant species.

Rice is of major importance in India today and was equally as important in antiquity. As discussed in Chapter two, the origin of rice is still under consideration but through genetic studies it is known that there are two or more domestication sequences (Chen et al. 1993, Cheng et al. 2003). One of these is likely to be within India and specifically within the two areas of study here. Parts of Uttar Pradesh and Orissa have populations of wild rice, especially *Oryza nivara*, which indicates that this broad region is the most likely place of domestication. Early archaeological evidence for rice is apparent in these areas and will be discussed in more detail in the next chapter.

A number of pulses could have originated in Orissa and Uttar Pradesh. One species that is clearly of East Indian origin is pigeon pea (*Cajanus cajan*). The wild form, *Cajanus cajanifolia*, can be found in the Bastar region of Chattisgarh, in Southern Orissa, and adjacent northern Andhra Pradesh (De 1974, van der Maeson 1980, 1986, 1990, 1995, Smartt 1985a, 1990, Jha & Ohri 1996).

It is not yet clear where *Vigna radiata* and *Vigna mungo* originated within India due to a need for new botanical investigations of their wild progenitors and a re-examination of old herbarium samples. The two wild progenitors, which are now known to be distinct species (Arora et al. 1973, Lukoki et al. 1980, Miyazaki 1982, Chandel et al. 1984, Poehlman 1991, Lawn 1995, Kaga et al. 1996, Ghafoor et al. 2002), used to be grouped together as *Phaeseolus sublobatus* or *Vigna radiata* subsp. *sublobata* sensu lato. They have also been suggested more recently to show differences in distribution (Arora et al 1973, Sharma et al. 1977, Ignacimuthu and Babu 1985, Babu et al. 1988, Arora and Mauria 1989, Fuller 2002a, 2003b, Fuller and Korisettar 2004). A new re-assessment of old herbarium samples has been initiated by Fuller (Fuller & Harvey in press) and reinforces previous evidence for distinct distributions but also suggests some overlapping areas. Populations of the wild *Vigna mungo* var. *silvestris* Lukoki, Marechal & Otoul, occur in the northern Western Ghats and extend in to the hills of Rajasthan stretching all the way to Mount Abu. It also occurs in the central Indian hills. Wild mungo co-occurs with *Vigna sublobata* (Roxb.) Verc. sensu stricto in the southern part of the Western Ghats. The wild form of *Vigna radiata* can be found in some of the Eastern Ghat hills and Western Himalayan foothills. These distributions may suggest that in the areas of study *Vigna mungo* is likely to be a component of early agriculture in Uttar Pradesh as its wild species is distributed towards the northern/western part of the Peninsula, where as in Orissa, *Vigna radiata* might be expected to occur earlier than *Vigna mungo*.

Another Indian pulse that may have originated in the study areas is *Macrotyloma uniflorum* Lam. Verdcourt (horsegram). The wild progenitor is thought to be native to Indian savannah zones (Jansen 1989) and Mehra (1997) suggests an origin in the southern and eastern peninsula. Recent re-examinations by Fuller (Fuller & Harvey in press) of herbarium specimens in Pune and Calcutta have suggested wild populations through Rajasthan, Madhya Pradesh, Maharastra, and southeastern Karnataka. If this information is combined with distributions of dry tropical evergreen and savannah vegetation then wild populations could occur over a large area including southern, northern, and eastern parts of India. More botanical studies are needed to isolate the true distribution of the wild progenitor for this pulse crop.

Tropical millets are also likely to be found in the deposits from the sites studied in this project. Although not indigenous to these particular parts of India, a number of species have been suggested to be native to Neolithic sites in Southern India. Fuller (1999, 2002a, 2003a, Fuller et al. 2001) suggests a crop package of two millets (*Bracharia ramosa*, *Setaria verticillata*) and two pulses (*Vigna radiata*, *Macrotyloma uniflorum*) for the initial phase of the Southern Neolithic. These two millets are minor crops today in parts of South India but are not always exploited in a domestic state (De Wet et al. 1983, Kimata et al. 2000). Some populations of *Bracharia ramosa* are domesticated in the sense of whole or partial loss of natural seed dispersal (Fuller 2003a), however *Setaria verticillata* is usually gathered from wild stands (Gammie 1911) and is rarely cultivated (Maheshwari & Singh 1965: 145-146). Both of these small millets are found in wild stands in the dry-deciduous zone and thorn scrub savannah. Today they are restricted predominantly to Western Peninsular India, but may have been more widespread in the past. The domestic form of *Bracharia ramosa* is grown by Hill tribes today in the Eastern Ghats of India (De Wet 1995a).

Other small millets such as little millet (*Panicum sumatrense*), kodo millet (*Paspalum scrobiculatum* L.), sawa millet (*Echinochloa colona* L. Link), and yellow foxtail millet (*Setaria pumila*) are also likely to have been exploited in the study areas. Little millet is grown in Burma and across India and Sri Lanka (De Wet et al. 1983a, De Wet 1995a) and is an important cereal in the Eastern Ghats of India. Its wild progenitor (*Panicum sumatrense* subsp. *psilopodium*) is still a weed of arable fields today and the domestic crop can be used as flour or boiled (or parboiled) like rice (Kimata 1989). Wild kodo millet grows throughout the tropics and Old World but the domestic form is only grown in India (De Wet et al. 1983b, De Wet 1995a). Sawa millet is cultivated throughout India but is also grown in other countries such as Egypt (De Wet et al. 1983c).

A number of Curcurbitaceae species are native to the Northern half of India including the Indo-Gangetic plain and Orissa. Macroscopic remains have been found of some of these species on Gangetic sites but usually from later levels. There is also the potential to look for these plants through phytolith remains as in Central and South America ancient cucurbits have been identified through phytolith analysis (Bozarth 1987, Piperno et al. 2000, Bryant 2003, Piperno & Stohert 2003). In this thesis, reference material will be sought of Indian cucurbits and the phytoliths will be examined to aid their identification in the archaeological samples.

The Curcurbitaceae species likely to come from India include vegetables and fruits such as cucumbers (*Cucumis sativus* L.), melon (*Cucumis melo*), and ivy gourd (*Coccinia grandis* L. Voigt.). However, many of these species require a lot more botanical investigation on their wild distributions to allow more definite areas of origin. Most of the species are thought to be of Asian origin but have no specific areas highlighted. The cucumber is probably the most likely of this family to have an Indian origin. The feral or wild variety, *Cucumus sativus* var. *hardwickii* has the same chromosome number as the domestic species and is found throughout the Southern Himalayan foothills (Bates & Robinson 1995). This suggests that Northern India may be a possible area of domestication for this species.

The wild progenitor of melon, *Cucumis prophetarum*, is distributed in Africa but also stretches to India and therefore it could also be domesticated in Northern parts of India (Bates & Robinson 1995, Choudhury 1996:151). Adding to the case for an Indian origin of melon is the fact that there are many Sanskrit terms including one for the wild species demonstrating that it was a commonly known plant in ancient times (Choudhury 1996, Decker-Walters 1999: 103).

Two species of *Luffa* may be of Indian origin. *Luffa cylindrica* (sponge gourd) is thought to have come from Southwest China, Southeast Asia, or South Asia. The wild progenitor of the angular gourd, *Luffa acutangula* var. *amara*, is found in India and this is its likely place of origin (Marr et al. 2005). Other gourds such as wax gourd (*Benincasa hispada*), bitter gourd (*Momordica charantia*) (Marr et al. 2004), balsam apple (*Momordica dioica*), and snake gourd (*Trichosanthes cucumerian* var. *anguina)* are all species that are distributed throughout most of Asia including India. The squash melon (*Praecitrullus fistulosus*) and pointed gourd (*Trichosanthes dioica*) have been suggested to have a more isolated origin and are thought to be native to India (Bates et al. 1995). All of the gourds are important summer crops today and provide food in the form of the fleshy fruit and the seeds are eaten of some of the species. Oil from some of the seeds is used for medicinal purposes, such as from the cucumber, which it is thought to be good for the brain and body (Choudhury 1996).

Sesame has been previously suggested to have its origin in Africa (Hiltebrandt 1932, Nayar & Mehra 1970, Mehra 2000) because of its great economic importance there but is now argued to be of South Asian origin as two unique sections of the genus *Sesamum* exist in India (Bedigen & Harlan 1986, Bedigan et al. 1985, 1986, Powell 1991, Bedigan 1998, 2000, 2003, Bhat et al. 1999, Hiremath & Path 1999, Zohary & Hopf 2000, Fuller & Madella 2001, Fuller 2002a, 2003b). Genetic proxy evidence supports this claim demonstrating that the cultivated *Sesamum indicum* is in a subgenus containing 26 chromosomes and also the fruit capsules are not ribbed and do not have protruding locules (Patil 1999). This work has also shown through hybidization experiments that *Sesamum mulaynam* Nair (= *Sesamum malabaricum*) has high compatibility with *Sesamum indicum* and therefore demonstrating it is the wild progenitor. More work is needed on the distribution of this wild form (Fuller 2003b) but it is currently thought to be found along the west coast of South India, the western part of the Himalayas, and a small population in western Pakistan. Sesame is a possible crop plant for the early sites in this study coming from Northern India.

Roots and tubers are an important part of the agricultural system in Eastern India and may have been some of the earliest cultivated species. In Asia, they can be grouped in to two main family groups: the Araceae and the Dioscoreaceae. Within the Araceae are the edible taros: *Alocasia indica* (Roxb.) Schott. (thought to be the same as *A.macrorrhiza*), *Alocasia macrorrhiza* (L.) Schott. (Giant taro), *Colocasia esculenta* (L.) Schott. (Taro), *Colocasia esculenta* var. *globulifera* (L.) Schott. (Dasheen), and *Cyrtosperma chammisonis* (Schott) Merr. (Giant swamp taro) (Plucknett 1976). The majority of these species are thought to originate in Southeast Asia but *Alocasia* spp. have been suggested to have come from India. The Asian species of the Dioscoreaceae are *Dioscorea alata* L. (Greater Yam), *Dioscorea bulbifera* L. (Potato or Aerial Yam), *Dioscorea esculenta* (Lour.) Burk. (Lesser Yam), *Dioscorea hispida* Dennst., *Dioscorea nummularia* Lam., *Dioscorea opposita* Thunb. (Chinese Yam), and *Dioscorea pentaphylla* L. (Purseglove 1972). Like the Asian species of taro, most of the yams are thought to have originated in Southeast Asia but Assam is included within the definition of Southeast Asia. The Greater yam is one of the species that may come from North-east India (Purseglove 1972: 100) and may have developed from *Dioscorea hamiltonni* Hook. or *Dioscorea persimilis* L..

Another possible indigenous crop is sugarcane (*Saccharum* spp). The origins of this crop are still problematic as a number of places in Asia have the wild relatives present. It was first suggested that the origin of *S. officinarum* was in New Guinea and that this species evolved from *S. robustum* (Brandes 1958). Then this domesticate travelled to China and India where introgression occurred with wild canes to produce *S. sinense* and *S. barberi*. More recent genetic work by Daniels and colleagues (Daniels & Daniels 1975, 1993, Daniels & Roach 1987, Daniels et al. 1974, 1980, 1991) has suggested that there is more than one origin of sugarcane. *S. robustum* is a hybrid of three wild canes: *S. spontaneum* L., *Erianthus arundinaceus* (Retz.) Jeswiet, and *Miscanthus sinensis* Andress. Not all of these taxa are native to the part of New Guinea thought to be the area of sugarcane evolution therefore there was some agent that brought these species together. It has been suggested that humans were the agent and brought in these different canes (Daniels & Daniels 1993). For example, *S. spontaneum* was used by prehistoric Taiwanese people as pig fencing and therefore it has been proposed to have travelled as part of the Austronesian package to New Guinea (Daniels & Daniels 1993). This is supported by linguistic evidence that suggests sugarcane as one of the elements of Austronesian dispersal (Blust 1976, 1984, Bellwood 2005: 142). Daniel & Roach (1987) first put forward that *S. barberi* was not a hybrid of *S. officinarum* and *S. spontaneum*. This means that it evolved independently in India and it was also found that it is related to *Erianthus* sp. It is therefore likely that there are three areas of origin for sugarcane: India, China, and New Guinea. Primitive species of *S. spontaneum* are found in the Himalayan foothills of northern India (Roach 1995). Phytolith remains of *Saccharum* sp. have been found at the sites of Kot Diji in Northwest India dating to 2930-2580 BC (Madella 2003).

Much recent attention has focused on the dispersal of bananas to Africa through the identification of phytolith remains and this crop is likely to have spread from India (Mbida et al. 2000, 2001, 2004, Lejju et al. 2006). Domestic bananas contain two different genomes (A and B) related to their wild progenitors, and from recent genetic studies, it has been suggested that *Musa acuminata banksii* F.Muell. was the wild progenitor of the A genome (Lebot et al. 1993, Lebot 1999). The B genome is proposed to have come from

Musa balbisiana Colla, which occurs wild in parts of India, Sri Lanka, Burma, and southwest China (Simmonds 1995). Relic populations of this wild banana species have been seen in Orissa, Eastern India by the author and have been reported to be used by tribal groups in Koraput, southern Orissa (Kornel 2006: 49). Early evidence of banana cultivation, presumably *Musa acuminata*, comes from Kuk swamp in New Guinea dating to about 5000-4490 BC (Denham et al. 2003, 2004). From South Asia, there is evidence of wild banana seeds from Sri Lanka demonstrating the possible use of *Musa balbisiana* as early as 10,000 BP by hunter gatherers (Kajale 1989) and also phytolith analysis has revealed *Musa* type morphotypes from Kot Diji, a Harappan site in Sindh (Madella 2003). However, these are likely to be domesticates because this region of South Asia would not have wild species present. Wild and domestic bananas could therefore have been exploited by the prehistoric peoples of Orissa and may also possibly be found at sites in the Ganges region.

The Palmae family has a number of species that are of economic importance and may have originated within Asia. There are many palms that are cultivated within India but here only the three most important species are highlighted. Coconut (*Cocos nucifera* L.) is an important crop throughout the humid tropics today and can be used for many purposes such as for its oil, water from the nut, and the heart of the palm can be eaten as well as the desiccated coconut (Harries 1995). Today India produces approximately one quarter of the world's coconuts. There is a large area in which this species could have originated including South America, the south west Pacific, and the Indian Ocean. Although, the most likely place is on the coasts and islands between Southeast Asia and the western Pacific (Harries 1995).

Date palm (*Phoenix dactylifera*) is another possible domesticate although only in Northwestern India. It is believed to be native to western India and the Arabian Gulf. There are about 12 species of *Phoenix* and there is much hybridisation between them (Wrigley 1995). The domestic species is very diverse and adapted to a wide range of environments. Little work has been carried out on the genetics of date palm. The fruits are the main product of this species and are divided into three groups on the basis of the characteristics of the fruit: soft, semi-dry, and hard. The wild date palm or forest date (*Phoenix sylvestris*) is used as a source of palm sugar that can be fermented in to toddy and maybe native throughout India.

Palmyra Palm (*Borassus flabellifer*) is a very useful plant and therefore has a large economic value. It has its origins within India and Malaya (McCurrah 1960). It is said to have 801 uses (Basu & Chakraverty 1994). These include: as food stuffs, as beverages such as jaggery and (alcoholic) toddy, and as fiber, wood, and paper (Davies & Johnson 1987, Basu & Chakraverty 1994). The mature stem is hard and termite resistant and therefore can be used in villages for making roof beams and semi-permanent structures (Basu & Chakraverty 1994). Evidence of its use can be traced back to prehistoric times when the palmyra leaf was used for Sanskrit writing (Davies & Johnson 1987). It is distributed throughout India but has large concentrations in Tamil Nadu, Andhra Pradesh, and generally the eastern side of India.

Early agricultural communities would have also adopted crops from outside of the Indian sub-continent. There are three main areas where crops have come from: Southwest Asia, Africa, and China/Southeast Asia (Hutchinson 1976, Willcox 1992, Fuller 2002a, 2003a, in press b). A crop package that might be found on the sites in this project is the Near Eastern crops. This group includes the cereals wheat (*Triticum* spp.) and barley (*Hordeum vulgare* L. sensu lato), winter pulses such as chickpea (*Cicer arietinum* L.), grasspea (*Lathryus sativus* L.), pea (*Pisum sativum* L.) and lentil (*Lens culinaris* L.), and also flax (*Linum* *usitatissimum* L.). A great deal of research has been conducted on the origin of these crops in South west Asia (Harris 1996, Hillman et al. 1997, 2001, Zohary & Hopf 2000) and this has been discussed to some extent in chapter two. This crop package spread in to South Asia and was well established by the Harappan civilisation dominating the agriculture of northwestern South Asia (Vishnu-Mittre & Savithri 1982, Costantini & Biasini 1985, Meadow 1989, 1996, Weber 1998, 1999, Tengberg 1999, Zohary & Hopf 2000, Fuller & Madella 2001, Fuller 2003a), however it is not clear whether they travelled as one distinct package or whether the cereals came first and then were followed by the pulses. The site of Mehrgarh in central Baluchistan shows the earliest evidence of Near Eastern crops. From the earliest levels, c.6000-7000 BC, there are plant impressions in mud brick. The majority of these are from barley, some being 6-row domesticated barley and some wild barley. Glume and naked wheats are also present. More flotation was needed when this site was excavated especially in the lower levels as no seed evidence was found. This lack of charred remains may bias against pulses and flax which are not present in any form. However, pulse remains have been found at Miri Qalat and could suggest a separate diffusion of pulses over a longer time period (Tengberg 1999). It is hard to interpret clearly what is happening during this period of spread from the Near East because there are so few sites with archaeology in Baluchistan.

This Near Eastern crop package spreads eastwards in to India by about 3000 BC. Evidence so far published, which is discussed in chapter four, shows it spreading along the Ganges River as far east as Bihar ca. 2000 BC. How far east it travels is not known because Eastern India is poorly sampled for archaeobotanical remains and hopefully this project will help to answer this question to some extent. Therefore this crop package is likely to be found at the Ganges Valley sites analysed in this project and may also be found in Orissa.

African crops were spreading over the Indian Ocean or Arabian Sea reach India by the early 2nd millennium BC (Fuller 2002a, Fuller & Madella 2001). Three important African millet crops and two pulses are seen in India: great millet (*Sorghum bicolor* (L.) Moench.), finger millet (*Eleusine coracana* (L.) Gaertner), pearl millet (*Pennisetum glaucum* (L.) R. Br.), cowpea (*Vigna unguiculata* (L.) Walp.), and hyacinth bean (*Lablab purpureus* (L.) Sweet). These crops have different regional origins and therefore different routes and times to arrive in India (Fuller 2003a, 2003c). Cowpea and hyacinth bean are widely cultivated in Africa today. Botanical surveys (Verdcourt 1970, 1971, Fuller 2002a, 2003c, Fuller & Harvey 2005) and new DNA evidence (Pengelly & Maass 2001, Maass et al. 2005) suggest an east African origin for *Lablab* where as Cowpea is likely to come from West Africa (Ng 1995, Fuller 2003c).

Chinese crops found in India are common foxtail millet (*Setaria italica* (L.) Beauv.), proso millet (*Panicum miliaceum* L.), hemp (*Cannabis sativus* L.), and rice (*Oryza sativa* L.). Rice has been discussed previously, but as well as a possible origin of *Oryza sativa* subsp. *indica* in India, japonica type rice could have spread from China. Hemp is indigenous to temperate Asia and was a valued fibre and oil crop in ancient times in China (Small 1995).

Common foxtail millet's closest wild relative is *Setaria viridis* (green foxtail millet). This species has a very wide range and could have been domesticated anywhere from Europe to Japan (de Wet 1995, 2000, Zohary & Hopf 2000, Jones 2004). *Setaria viridis* is found in the Southwest China (Chang 1983). *Panicum miliaceum* is thought to be indigenous to North China and possibly also in Europe (Chang 1983, Jones 2004). *Panicum spontaneum* may be its closest relative.

Both *Setaria italica* and *Panicum miliaceum* are adapted to semi-arid and infertile soils. This means that they prefer dry temperate regions with summer rainfall and long cold seasons. They have a short growing season, which makes them very good for primitive cultures as they need less attention than other types of crops and can be grown over short periods of time. These millets were particularly important in the Yangshao period where shifting and repetitive occupation did not hinder their cultivation (Li 1983). Early finds of common foxtail millet and proso millet in China mean that they are likely to be domesticated in this area and then spread west in to India (Lu 1999).

3.6 Palaeoclimate and palaeoenvironment

Palaeoclimatic and paleoenvironmental evidence for India is limited but it is clear that the climate at the end of the Pleistocene and beginning of the Holocene was not uniform throughout the sub-continent (Chakrabarti 1999: 95). A great deal of the recent studies have focused on the Northwest region of India because climate change has been seen as a key factor in the rise and fall of the Harappan civilisation (Singh 1971, Singh et al 1974, Bryson & Swain 1981, Agrawal 1982, Swain et al 1983). However, this view has been criticised by many archaeologists (Misra 1984, Paddaya 1994, Possehl 1997a, 1997b, 1999, Fuller & Madella 2001, Madella & Fuller 2006) and more detailed re-examinations of the available data is leading to a different view. The majority of the evidence for palaeoclimate and palaeoenvironment has come from the salt lakes of Rajasthan and Gujarat such as Bap-Malar playa (Deotare et al. 1998, 2004a, 2004b), Sambhar Lake (Singh et al. 1974), Didwana Lake (Wasson et al. 1984, Singh et al. 1990) and Lunkaransar Lake (Enzel et al 1999). Madella & Fuller (2006) suggest that there are problems with using sedimentological data for implying climate change because the drying of these lakes is not always related to the climate and can be the result of more local tectonic changes. Palynological studies tend to have more of a regional focus and can therefore be used to show climatic patterns. The general pattern that has come out of these studies is that during the Last Glacial Maximum and the Younger Dryas there were dry periods in which the Lakes were generally dry or held little water, the environment was dominated by grasses, sedges, Chenopdiaceae, and Artemisia. This was followed by a long much wetter period in the early Holocene although there were some brief arid episodes within this period such as about 6000 BC. The middle Holocene, from about 5000 BC, was an even wetter phase showing high levels of water at Didwana and Lunkaransar Lake. These wet conditions, especially the increase in winter rainfall, may have encouraged pre-Harappan villages to conduct winter-spring agriculture. Then approximately 3000 BC a drier period begins. Madella & Fuller's (2006) re-examination of the current data has led them to conclude that the Harappan civilisation began in a time of drying conditions. There was a decline in the rainfall by the time of the Mature Harappan period, which may have caused the establishment of more urbanism and centralisation. This is a potential climatic pattern that could be applied to other regions of India and the evidence from other areas can be compared to this general climatic pattern of change.

There are some studies for the Gangetic plain and it is clear that there has been considerable movement of the Ganges River, which would have affected the water supply and therefore environment throughout the plain. Therefore, this needs to be taken in to account with any palaeoenvironmental study because the changes in environment may be the result of tectonic movements rather than climatic changes.

It has been suggested that there are a number of tectonic movements in the Ganga Plain. The most important for this thesis are the movements within the central alluvial plain. A number of lakes and ponds formed from evolving river channels during 8000 to 5000 BP (Singh 2005). However, tectonic movement in this same period meant that these lakes became cut off from their water supply. From about 5000 BP, these lakes reduced in size and became much smaller ponds because of increased siltation and also a drier climate.

While these lakes would have provided good habitats for wild rice species, this may have contracted as they shrunk especially for *Oryza rufipogon*, although populations of *Oryza nivara* may have expanded.

As in the Northwest of India, there have been palynological studies conducted on lake sediments from the Ganges plain such as Sanai Lake (Sharma et al. 2001, 2004), Basaha Lake (Chauhan et al. 2004), Misa Tal (Singh 2005), Lahuradewa Lake deposits (Singh 2005) and Sarai-Nahar-Rai (Gupta 1976). This has enabled the reconstruction of palaeoenvironment over the last 15,000 years (see figure 3.7 for a diagram of palaeoenvironmental data from the Ganges region). Throughout this period there was a general pattern of open grassland with a few forest patches (Singh 2005). The pollen analysis has demonstrated that these lakes are thought to have formed around 8000 BP and had swampy areas surrounding them. Some of the lakes expanded during 7700 and 6600 BP and then there was a reduction after 6000 BP. This may have something to do with tectonic changes and also a drying climate at this time. It has been suggested from pollen studies that it was a rich environment with grasslands, swamps, and forests (Gupta 1976). Agricultural activity has also been proposed from the beginning of lake formation at most of the locations (Singh 2005) but this is based on the appearance of so-called "cerealia" pollen and also "rice" phytoliths. There are certain problems with using both of these remains as indicators of agriculture. The rice bulliforms could be mis-identified and may in fact be a wild species of rice or another grass from the Oryzeae tribe (see chapter six for further discussion on the problems of rice identification methods). The identification of cereal pollen is also problematic. Pollen can be used to identify landscape changes associated with agriculture such as forest clearance but it is difficult to identify specific cereal species. Few grass species can be separated using pollen because the grains are very similar and are only distinguished on size, which is not an accurate method because of intra-species variations. This is especially true in India where there are many wild polyploid grasses that have large pollen grains, which overlap with the European cereal size range and also some India crops such as rice and small millets have small pollen therefore in the wild size range (Vishnu-Mittre 1974, 1976a, 1976b, 1981a, 1985, Vishnu-Mittre & Guzder 1975, Vishnu-Mittre & Sharma 1983, Maloney 1990, 1994). Therefore, neither "rice" phytoliths nor "cerealia" pollen can be used in this way to indicate agriculture.

These changes in the landscape, and particularly the formation of lakes, seem to coincide with the peopling of these areas. From approximately 8000-7000 BP, Mesolithic sites are found in this region close to the lakes such as Sarai-Nahar-Rai. Another important aspect of this change in the landscape was that it created an environment that would have suited the wild rice species *Oryza nivara*, which may account for the supposed change to cultivated rice bulliforms in the Lahuradewa sequence. This change may in fact indicate the shift from *Oryza rufipogon*, which requires year round wet conditions, to *Oryza nivara*, which is better suited to seasonally flooded areas. This could have been exploited by the ancient people and may have been the start of a closer relationship between wild rice plants and humans in this area.

3.7 Tribal groups

Typical descriptions of modern tribal groups focus on these people demonstrating primitive existence that can be used to infer past hunter-gatherer societies. Examples are often based on pristine and isolated groups from Africa (Lee 1969, 1979) or Australia and South Asia is normally overlooked because the tribal groups are thought to be less "pure" and therefore not as useful for analogues (Morrison 2002). The isolation of hunter-gatherers is a currently debated topic in the literature (Bailey et al. 1989, Townsend 1990, Barton 2005) and has been discussed in chapter 2 in relation to the ability to exist in isolation in tropical rainforests. The majority of tribal groups today do not exist in isolation and are part of complex economic systems but should this prevent them being studied? Morrison (2002: 10) suggests that studies of these groups can be used to help investigate archaeological questions. It is the way in which the study is approached and how the data is used that has to be changed. She proposes a multidisciplinary approach to take in to account long term histories, environmental and ecological issues, as well as situating the groups in a political framework (Morrison 2002: 6). These groups should not be seen as primitive because they have been constantly developing over long time scales and are usually a complex mix of varying economic strategies. The only truly isolated hunter-gatherers today are those on the Andaman Island off the east coast of India (Bose 2002).

Another consideration is the categories that groups are put in to and whether they are really appropriate to explain the economic systems used. The non-pristine groups are a good example of how it is very hard to classify tribal groups in to certain categories. Morrison (2002) points out that normally the so-called more advanced element gets priority therefore groups that are predominantly foragers but practise a small amount of agriculture will be called agriculturalists. This is also true of foragers who trade, who are often called specialists or traders (Morrison 2002: 12-13). It is particularly important that these rigid categories are avoided in archaeological studies because transitional societies may have been practising a combination of these different modes.

Here a summary is presented of the tribal groups found in the regions of study. It is clear that they practise a number of different economic strategies and these usually involve a mixture of different modes of subsistence. There is a focus on the economic strategies used and the scheduling of agricultural activities during the year, which are summarised in tables that can be found in figure 3.8 and 3.9.

There are a number of different language family groups spoken in the India sub-continent including Indo-European, Austro-Asiatic (Munda), Dravidian, and Tibeto-Burman. Most of the tribal groups speak minority languages such as languages in the Munda family although some have adapted majority languages. This implies intensive contact and exchange with settled majority groups predominantly plains farmers. All of the Munda languages have ancestral agricultural vocabulary within them (Zide & Zide 1976) as do the majority of Dravidian languages (Southworth 1976, Fuller 2002b). An example of this is the appearance of some South Asian pulse names in proto-Munda vocabulary. Black gram (*Vigna mungo*) and a red pulse, which may be *Cajanus cajan* both feature in the language (Fuller 1999, 2002a, 2002b). A new model has been put forward by Fuller (2002b), which suggests early Dravidians to be more 'Mesolithic' than previously thought. Reconstructed vocabularies suggest practises that occurred prior to agriculture such as the use of wild seeds and tubers including technology for dehusking, threshing, and grinding (Fuller 2002b: 207). Other agricultural terms have been borrowed from proto-Munda languages suggesting that agriculture was probably earlier in these Munda speaking groups than in the Dravidian groups. This means that Orissa, as the area with the greatest number of Munda speaking tribal groups, is an important area in terms of early agriculture.

Tribes in India have become known as 'scheduled tribes' which, is a tribe that is recognised in a list of tribes declared by the government (Mehta 2004). In the 1951 census, the population of scheduled tribes was 5.3% (19,147,054 persons) of the total population. This has increased to 8.01% (67,758,380 persons) in the most recent survey taken in 1991. The majority of the tribal people live in Northeastern India. The state of Mizoram has the highest percentage of scheduled tribes; 94.8% of the population.

Uttar Pradesh only has a small tribal population. In the 1991 census, 0.02% of the population was recorded as scheduled tribes (Mandal et al. 2002). There are only five tribes in this area: Tharu (Indo-European), Bhotia (Sino-Tibetan), Bhoksa (Sino-Tibetan), Raji (Sino-Tibetan), and Jaunsari (Indo-European). Most of the Gangetic plain is dominated by non-tribal people and this may be the result of the lack of forested areas. Tribal groups occur in small numbers over Uttar Pradesh but the same tribal groups have much larger numbers in Uttaranchal to the north of the state. These groups are all dependent on settled agriculture and animal husbandry for their survival. The languages spoken vary for each group but there are similarities between the language groups of some of the tribal people. The languages of the Jaunsari and Tharu are both from the Indo-Aryan language group but differ from the dominant Hindi. Bhotia and Raji tribes speak languages that are based in the Tibeto-Burman language family and the Bhokas speak Hindi.

Orissa has a considerable amount of tribal people making up 22.43% of the population (Mandal et al. 2002). Over 50% of these people live in the highland belt, which includes some areas of dense forest. The highland belt is located in the districts of Mayurbhanj, Koraput, Sundargarh, Keonjhar, and Kalahandi. These people have relied mainly on the forest and forest products in the recent past but in some areas increasingly practise settled cultivation, which correlates with deforestation. Orissa has 63 scheduled tribes and the five tribes with the largest populations (Census 1991) are the Khond (of the South-Central Dravidian language family), Gond (of the South-Central Dravidian language groups) in the South, and Santal (Munda), Kolha (Munda), and Saora (Munda) in the North and West (Mandal et al. 2002). Within Orissa the tribal groups practice a number of different economic strategies. Figure 3.8 shows a table of some of the tribal groups that are found in Orissa and surrounding areas indicating the modes of subsistence used in the recent past. It is clear that they fall into two main groups as can be seen by the archaeological categories given at the end of the table. The first category is the 'hunter-gatherers' although a better description is forager-traders. These groups rely on hunting and gathering forest products for their livelihood but a large part of their diet including the staple of rice is procured from nearby agriculturalists. This raises the question as to what the ancestors of these groups did before they traded for their staple crop. Were they previously fully reliant on forest products, and the decline in forested areas has stopped this way of life, or were they previously practising some agriculture but have become increasingly specialized forager-traders. The linguistic information mentioned above suggests these groups have been agriculturalists in the past due to ancestral agricultural vocabulary (Fuller 2002b) and therefore their present occupation is probably a relatively modern transformation.

The other type of tribal group that exists today and probably gives more insight into what these groups would have been like in ancient times are those that practise agriculture. The predominant method is shifting cultivation but some intensive irrigated methods are used to produce rice. What is interesting about these groups is that they are often not purely agriculturalists. They also rely on forest products, and trade. This means that they have rather complicated modes of subsistence but these may provide useful analogies for potential Neolithic systems.

As mentioned above, some of the tribes in Orissa still predominantly practice foraging (Patnaik 2005), although this is not their only mode of subsistence. These groups are the Birhor (Munda), Chenchu (Dravidian), Mallar (Malto, North Dravdian), Korwa (Munda), and the Hill Kharia (Munda) of Sundergarh and Mayurbhanj. They are small in number, approximately 10,000 individuals and are nomadic, travelling in small groups. They live in bamboo huts and leaf shelters. These groups are not completely isolated and tend to trade with neighbours. In Orissa, usually in these groups, males do hunting as their main task where as females are concerned with gathering root and tubers. It has been suggested that no storage of supplies seems to take place as they have a lack of concern for food shortage but this may just be an urban myth (Patnaik 2005:18) and trade probably fills in lean periods of wild exploitation. The Birhor trade hunted animals and make items out of forest products such as rope and baskets to trade for staples such as rice with their neighbouring farmers. In recent years, this group has also been employed for catching Rhesus monkeys for scientific research.

Larger numbers of tribes exist today in Orissa practising shifting cultivation on hill tops and slopes including both Dravidian and Munda language groups: Dongria and Kutia Khonds (both Dravidian), Lanjia Saoras, Juangs, Bondo Paroja, Bhuinys, and Bhumijs (the rest are Munda speaking tribes). This type of agriculture is called *podu* cultivation in Orissa (Mandal et al. 2002). All activities with this type of agriculture are preformed on a communal basis. A hill is selected each year for cultivation at a village meeting. Sometimes fields are divided in to families at the consent of the community. The process involves slash and burn agriculture, and the use of long sharpened sticks (hoes) to loosen the top soil. The seeds are then broadcast in to the fields. After two to three years when successively different crops are sown, they will shift to another field. Individual plots are hereditary but fallow plots are communal. This type of agriculture is preferred over other forms because it produces a variety of edible crops with minimal effort (Mandal et al. 2002). Mixed crops consist of millets, pulses, and vegetables and particular plants are grown because of food habits and ecological conditions (Patnaik 2005: 20).

When looking at the forms of agriculture practiced by these tribal groups, it is clear that they are using the natural environment and local habitats to the fullest extent and not investing greatly in agriculture but just exploiting the natural conditions. Although, swidden involves a lot of time investment to grow and tend the crop, it is conducted in a basic manner such as with hoes and does not involve the same initial investment as with the creation of an irrigation system. Any agriculture that is practiced uses low technological methods. A good example of this is the economic system employed by the Juangs. Juangs are only found in Orissa and are confined to Keonjhar and Dhenkanal districts. During the colonial period, their economic strategy was largely based on forest products but due to a decline in natural resources, agriculture has become their dominant mode of subsistence again (Patnaik 2005).

Juang settlements are located on foot hills or hill slopes and close to a source of water. Settlements used to frequently move within the village boundary to be close to the swidden patch being cultivated (Mehta 2004). Now Juangs have permenant settlements because of legal land holdings given to them by the state government.

The Juangs recognise five different land types that can be cultivated. There are *ekan* (swidden land), *bila* (wet land), *gaddak* (plain unirrigated cultivable upland), *bakadi* (manured land next to settlements), and *muji bakadi* (kitchen gardens) (Mehta 2004:290). The *bakadi* is for crops that are reliant on rain water and includes crops such as maize, mustard, and horsegram. Maize is sown in late summer (June) and harvested during September. Mustard is then sown in September/October and harvested during December. Kitchen gardens are grown around the homesteads and they grow seasonal crops and a large variety of vegetable crops. These crops include pumpkin, ash gourd, bottle gourd, taro, yam, ginger, turmeric, papaya, banana, and other vegetables. *Bila* and *gaddak* are used for rice and occasionally wheat. The wet lands are seasonally inundated lands close to rivers. In this land, two crops of rice can be grown each year.

The majority of the Juangs' time is spent on their swidden cultivation (shifting cultivation). Family labour is generally employed for all swidden activities but communal help is extended with remuneration. Women do most of the agricultural work except for ploughing and sowing. The Juangs believe that if women sow crops then the soil will lose fertility (Mehta 2004). Two plots are used every year on the hill slopes. They have a set pattern of cultivation for swidden plots. The principal crop in the first year is *Guizotia abyssinica* (Niger), which is sown in June/July and harvested in November/December. This crop can be grown with others around the edges of the plots with *Vigna umbellata* or *Vigna mungo* in the middle, but is usually grown in a separate plot. In ditches, taro (*Colocasia esculenta*) is grown and sweet potato (*Ipomoea batatas*) is grown near the niger plots. During the second year the plot is used to grow rice and pigeonpea, which is sown in May or June. These crops are grown with cucumber and bitter gourd in the middle of the plot. A number of millets and pulses are grown around the edge of the plot: *Eleusine coracana*, *Setaria italica*, *Sorghum* spp., *Vigna mungo*, *Pennisetum typhoides*, *Vigna unguiculata*, and *Vigna umbellata*. In the third year, *Guizotia abyssinica* is grown again and after this crop the land is left fallow for five to seven years. Another plot is selected for cultivation; therefore in this case it is the field that shifts not the settlement (Bose 2002: 14). Villages in Orissa do occasionally move but this is a rare occurrence today. Tribes in northeast India are more likely to move more frequently but again this was more likely to have occurred in the past.

This agricultural system provides the tribe with four months worth of food. A large amount of the produce is consumed but maize, mustard, and niger are traded for other goods at the nearby market. Forest products account for another two months worth of supplies and then the rest of the year is spent in hunger or an earning source is found outside the village (Mehta 2004). This is a problem that results from modern land restrictions and therefore was probably different in the past.

Figure 3.9 shows examples of two different agricultural schedules for two tribal groups. The Paharia only practise swidden cultivation but the activities are spread throughout most of the year with only January being free of agricultural work. They start to clear fields much earlier in February than the Bondo's do with their swidden plots. This is surprising that the work is spread out so much and may well be the result of this tribe being sedentary and therefore having all year in the same location.

The Bondo practise two types of agriculture: swidden and irrigated methods. Their agricultural regime is also spread out throughout the year but swidden is restricted to a shorter period because the other fields need to be planted before them. The beginning of the year is dedicated to the irrigated fields and the swidden plots are not cleared until April.

3.8 Summary

India is a diverse sub-continent with mountain ranges, river valleys, and coastal plains. The particular regions of focus in this project are equally as varied. The Belan River Valley is part of the vast Gangetic plain, which provides a ready supply of fertile alluvium for cultivation. This area seems to have been populated after a drying of the climate that created lakes and good environments for annual wild rice. Orissa is a mix of highlands with patches of dense forest and the coastal lowland area, which has river channels, lakes, and mangroves. Both regions have fairly high rainfall that is determined predominantly by the summer monsoon. This means that these areas have rich tropical environments with many exploitable wild resources such as wild rice, fruits, roots and tubers. Some areas, such as the alluvial plains of the Ganges River Valley and the coastal plain of Orissa, are preferred for more intensive permanent cultivation where as more upland areas such as the hills of North Orissa are used for shifting cultivation. These environments are produce vast amounts of agricultural produce today and therefore have the potential to be exploited for agricultural land in the past.

There is the potential for the development of many indigenous crops in both regions and also for many crops to be introduced. It is likely, as indicated from previous evidence that initial cultivation concentrated on indigenous monsoon season crops. This will be discussed in more detail in the next chapter with archaeobotanical evidence from the Gangetic region as well as a review of current archaeological evidence from both of the study areas.

Chapter 4

Early farming communities in Northern and Eastern India.

There is a growing wealth of data on early farming communities in India. This goes some way to start to explain the development of agricultural subsistence but there are still many holes in our knowledge and a lot of conflicting information. Many excavations have been conducted in the Gangetic valley, especially Uttar Pradesh. This has proved a close link between the sites in this region during what has been termed the "Neolithic and Chalcolithic" periods. However, accurate dating of these sites is definitely still an issue and therefore a refined chronology is still not obvious. This produces problems because it means that it is hard to investigate other issues, which require sequences of dates such as the development of pottery wares and agricultural systems on a regional basis. A review of the available published dates will be conducted here as well as a critical assessment of published botanical data from these sites.

Orissa has a different problem as very little is known about the early farming communities in this area. Few excavations have taken place and therefore it is still hard to make assumptions about how sites relate to each other. However, a review of the available information is presented here, highlighting similarities and differences throughout the relevant time periods and over different parts of the state.

During these reviews the terms defined by the excavators will be used for periods of the site such as Mesolithic, Neolithic, and Chalcolithic, and these terms are commonly used in Indian archaeological literature. These terms are usually applied in a very general way and sometimes do not fully explain phases appropriately. Generally, the Mesolithic period refers to deposits that have microliths, but they can also have crude pottery, and polished and ground stone implements, which are sometimes thought of as elements of the Neolithic. This phase usually does not have structural elements but this also varies from site to site. The Neolithic is used to refer to the period when farming appears although hard evidence to indicate farming is rarely available. A well developed pottery industry, polished stone tools, bone tools, and ground stone implements are all common. However, sometimes stone tools are not present and bone tools are more common such as at some sites in Orissa. Cord impressed wares are thought to be a defining element of Neolithic culture but do continue into other phases. These sites usually have some structural evidence. The Chalcolithic is when copper appears at sites and this period can have the same material elements as the Neolithic in every other way. At some sites new pottery wares appear such as white painted black and red ware that is a feature of the Narhan culture. This period generally has a well-developed agricultural base and many structural elements are also present. Giving names for specific cultures is more helpful for comparing sites and relates better to the actual material culture elements found at sites. These terms will also be used and developed during this review to aid the distinction of relationships between sites.

4.1 Early farming settlements in the Ganges Valley

There has been a long history of exploration and excavation in Uttar Pradesh. This started as early as 1860 when Le Mesurier discovered Neolithic celts near to Allahabad on the Tons River (Le Mesurier 1961, Pal 1986). A number of rock shelters with painted depictions of animals were also found in the 19th century in Mirzapur by Carlleyle (Brown 1889) and Cockburn (1883a, 1883b). These caves contained microliths and also crude handmade pottery (Smith 1906). Early work was also conducted by Ghosh (1932), who described a number of rockshelters including Lekhania and Mehdariya in Mirzapur. The first systematic study of the area was conducted by the University of Allahabad and this work has continued to the present day. These studies have included extensive surveys of river valleys, and the excavation of a large variety of sites. This work began in the 1950's with surveys of Banda, Allahabad, Mirzapur, and Varanasi districts of southern Uttar Pradesh, which discovered Mesolithic open-air settlements, rockshelters, and Neolithic sites (IAR 1955-56: 4, IAR 1956-57: 14). It was not until the 1960's that excavations started to be conducted and preceded on a number of sites such as Chopani Mando (IAR 1966-67:38) and Lekhahia (Misra 1977). During the mid 1970's a number of important Neolithic sites were excavated; Koldihwa, Panchoh, and Mahagara. These sites established for the first time the elements found within Neolithic deposits from this region such as the specific pottery types and stone implements (Sharma & Mandal 1980, Sharma et al. 1980a). More recent excavations from the University of Allahabad has concentrated on the sites of Tokwa (Misra et al. 2000, 2000-2001) and Jhusi (Misra et al. 1996, Misra et al. 1998-1999).

Other surveys and excavations have been carried out in northern Uttar Pradesh by Rakesh Tewari and colleagues from the U P State Archaeology department in combination with a number of Universities. Recent work has included the excavations of Lahuradewa and Malhar (Tewari et al.1999-2000, 2001-2002, 2002-2003, 2003-2004a, 2003-2004b). Both are important sites in terms of the development of the Neolithic culture in this region, which will be discussed further below.

The transition to farming is still rather unknown in the Ganges Valley although there is growing evidence for the spread of agriculture towards the east of the country. There are a number of sites with "Mesolithic" phases that have been excavated in the Middle Ganga plain and these sites will be discussed later in this chapter. Further to the south, in the Belan River Valley, the site of Chopani-Mando is of importance because it is thought to show the start of rice cultivation through wild rice exploitation and this is thought to have developed into an agricultural practice at the two nearby 'Neolithic' sites of Koldihwa and Mahagara (Sharma et al. 1980, Kumar & Pant 1999-2000, Kumar 2000-2001). This is the only potential evidence of a transition to farming in this region. Chopani-Mando is located on a small tributary of the Belan River, 77km southeast of Allahabad (Sharma et al. 1980a, Sharma & Misra 1980). The site has three main periods starting in ca. 17,000 B.C with an Epipaleolithic phase producing blades, points, and scrapers. Subsequently, there is a microlithic period with some evidence of structures, non-geometric and geometric microliths. Period three has the appearance of crude ceramics and the continuance of microliths. This last period is termed the 'advanced Mesolithic' and could be contemporary with the settled farming sites of the Belan River Valley. Deposits at this site are not substantial, although there is evidence for some structures and therefore it is likely to represent a seasonally settled hunter-gatherer site rather than a permanent settlement.

The other relevance of this site is the early appearance of crude ceramics, which are different to those found at the early farming settlements in this region and could demonstrate the first appearances of pottery in this area. Ceramics have been found in other hunter-gatherer sites in this region such as Morahana Pahar, Baghai Khor, Lekhahia, and Ghagharia rock-shelter (Pal 1986), and therefore is likely to be a development originating in this period before the start of the early farming settlements. The pottery found at these sites is all very crude. It is all handmade and uses non levigated clay. There are two main wares; brownish grey ware and ochreous red ware. Some of the pottery has cord impressions or incised designs. This pottery could be considered the initial stages of pottery development in this area but the shapes, decorative motifs, and the size of the pots bare little resemblance to the later Neolithic pottery, which is much more advanced. This has been considered to suggest there is no influence from this Mesolithic society on the

Neolithic people (Pal 1986: 87-88) or that the earlier pottery was just inspiration (stimulus diffusion, sensu Kroeber 1940) for making their own pottery rather than direct diffusion.

There is little evidence for the exploitation of plants at Chopani-Mando. Wild rice grain impressions in pottery have been reported as well as a number of wild animal remains (Sharma et al. 1980a, Sharma & Misra 1980) although rice impressions of any sort appeared rare in the sherds from the author's recent re-evaluation. Re-examining this site for archaeobotanical remains may reveal evidence for the exploitation of wild plants and of particular importance is to establish the use of wild crop progenitors such as wild rice. Consequently, this site has been systematically sampled for archaeobotanical remains, which is discussed in more detail in chapter five.

Chopani-mando also needs to be considered in relation to other hunter-gatherer sites in the region. A number of sites surrounding the horse-shoe lakes in the Middle Ganga plain have been suggested as regular habitation sites for foragers. Sarai-Nahar-Rai, Mahadaha, and Damdama all produced evidence of structures, such as burnt plaster floors and hearths, as well as a considerable number of burials (Sharma et al.1980b, Varma et al. 1985, Lukacs 1992, Lukacs & Pal 1993, Chattopadyaya 1996, Pal 2002). The lack of burials at Chopani-Mando may indicate that this site was not used in the same manner as these other examples, e.g. as a seasonal camp. All the Middle Ganga plain sites contain evidence of wild animal exploitation, especially deer and gazelle (Chattopadyaya 2002), and at Damdama evidence of the foraging of wild seeds and roots has been suggested (Kajale 1990). Damdama also offers evidence for chickens in the later levels (Thomas et al. 1995) and this may suggest early chicken husbandry at this site. Evidence for early cultivation and husbandry may be present at all these sites and should be investigated further.

Dating evidence for these forager sites is controversial (a table of all available dates can be found in figure 4.1). An early date from Sarai-Nahar-Rai (10,050 ± 110 BP) is considered unacceptable but late Holocene dates have also been questioned (Agrawal 1982a, 1982b, Possehl & Rissman 1992, Chattopadhyaya 1996). For Mahadaha, an accelerator date has been taken from a charred animal bone giving an age of 6,320 ± 80 BP (Chattopadhyaya 1996). Thus, a middle Holocene date has been suggested for this site and as a result for Sara-Nahar-Rai and Damdama because of the similarities between all of these sites. However, some forager sites do produce exclusively late Holocene dates, such as Lekhahia, and therefore these sites may be later. This should not be seen as a problem because foragers could overlap with the early farming culture in this region as may be demonstrated at Chopani-Mando but it is also equally likely that there is a considerable time gap between the Mesolithic sites and the Neolithic sites discovered so far.

From the hunter-gatherer, semi-sedentary sites, there is a move towards sites with more sedentary occupation, which have a developed agricultural system. However, there are certain problems with these sites, which make it complicated to form a clear chronology. The dating evidence is contradictory and does not form a clear sequence with the earlier hunter-gatherer sites. The artefactual evidence does not follow on from the hunter-gatherer sites either. Therefore, it is likely that there is a gap of some time between the 'Mesolithic' occupation of this area and the later sedentary sites. There are also few sites that demonstrate the initial phases of this 'Neolithic' Phase and this will be discussed in more detail below.

The early farming settlements of the Vindhyas culture are characterized from evidence of over 40 sites in the Belan, Adwa, Son, Rihand, Ganga, Lapari, and Paisuni valleys in Uttar Pradesh (a map of the sites mentioned in the text can be found in figure 4.3

and a timeline for Ganges sites can be seen in figure 4.4). The main characteristics of the Vindhyas culture, defined by the Indian excavators, are sedentism, characteristic pottery (cord-impressed, rusticated, black burnished, and red burnished ware), rounded polished stone implements, Neolithic blades, and an economy based on domesticated cattle and rice agriculture (Pal 1986, Pandey 1988, Allchin & Allchin 1997, Mandal 1997). This project is focused on two early farming sites in the Belan River Valley: Koldihwa (IAR 1975-76, Vishnu-Mittre & Savithri 1975-76, Misra 1977b, Sharma et al. 1980a, Pal 1986), and Mahagara (IAR 1975-76, IAR 1981-82, Sharma et al. 1980a, Pal 1986). Current evidence seems to suggest that sedentary agriculture, including domestic cattle (Chattopadyaya 2002), occurs at these sites from the mid/late third millennium BC but what is at issue is when sedentism occurred, when ceramic production began, and when the transition from the foraging of wild rice to its cultivation and the morphological domestication of rice happened, and when cattle became domesticated. How these transitions are related to one another should also be considered. Therefore, systematic sampling for the recovery of archaeobotanical remains has been conducted at Koldihwa and Mahagara to address these issues and more details of the methods used can be seen in chapter five.

Before we can start to discuss the cultural elements of these sites, a chronology needs to be established. There has been considerable controversy over dates of sites in the Middle Ganga valley (Allchin & Allchin 1982: 118, Pandey 1988, Kajale 1991: 169, Mandal 1997, Singh 2001, Fuller 2002a: 299), which have been claimed to have the earliest evidence of rice domestication in India (Sharma et al. 1980a). Early radiocarbon dates reported by Sharma et al. (1980a) for Koldihwa have been considered to be unreliable by many scholars (Possehl & Rissman 1992, Glover & Higham 1996: 416, Bellwood 1996: 488, Fuller 2002a: 299). The beginning of the early farming culture in this area has therefore been considered to date to around 4^{th}-3^{rd} millennium BC because of more reliable dates published for Khunjun II (Possehl & Rissman 1992) and a single AMS date from a sherd of rice tempered pottery from Khairadih (Bellwood et al. 1992). A table of the radiocarbon dates for the sites discussed is in figure 4.2. However, recently excavated sites in the Central Ganga Plain, Lahuradewa and Malhar, have produced dates of 6th - 5th millennium BC based on three bulk charcoal dates (Tewari et al. 1999-2000, 2001-2002, 2002-2003, 2003-2004a, 2003-2004b) and flotation sampling at these sites has produced evidence for the presence of rice (although further work is needed on its domestication status). The single date of 5474 BC from Malhar was not taken from a primary cultural deposit. In fact, it was not part of the cultural sequence found at the site and has therefore not been used to date it. Period one of Malhar starts between c.2200 and 1800 BC and the earlier date has not been related to the artefacts found. Although it may suggest human activity on the site at this time, there is no clue what this was as the excavators suggest the "organic material happened to be trodden from some unrecorded area of early human activity and randomly dumped in the pit by the settlers" (Tewari et al. 2003-2004b: 186-187). This date should therefore be discounted as a Neolithic date as it does not correspond with the site that was actually excavated.

There are also problems with the dates from Lahuradewa. Although the early dates come from charcoal in deposits of period IA, there is 2000 years between these dates and the dates given for period IB. These two periods are extremely similar in artefacts and the excavators have even said about the ceramic industries that "the tradition of earlier phase continued to occur in almost the same proportions and variations" (Tewari et al. 2002-2003). It is hard to believe that this continuation occurred for 2000 years and the deposits are not substantial enough for this length of time. Even the two dates that have been produced for Period IA are 1000 years apart and therefore it can be surmised that this phase should be re-dated to check the peculiarly early dates, which could easily be the result of the old wood effect.

The evidence from Koldihwa also suggests that the early dates are not accurate. Again, from the early dates of the 6th millennium BC through to the later dates of the 2nd millennium BC is a long time period and would need to present substantial deposits. Such large deposits are not present either at Koldihwa or Mahagara. Consequently, if we are to accept the early dates there must be a gap in the cultural sequence at some point. This is not obviously apparent looking at the material culture, which is consistent throughout the deposits. It is more likely that these early dates are still incorrect and that there is in fact a shorter span of occupation starting in 4th - 3rd millennium BC based on dates from Khunjun II (Possehl & Rissman 1992). A re-examination of the evidence from these sites along with additional archaeobotanical work will hopefully establish a clear chronology and whether there is evidence for an independent rice domestication in this area.

It can therefore be suggested that the deposits of settled agricultural sites start to appear in the 4th-3rd millennium BC. As mentioned above, there are few deposits that show the initial phase of Neolithic farming, which seems to suggest subsistence solely based on rice as well as an established pottery industry. Deposits of this type are thought to come from Koldihwa and Mahagara but no systematic archaeobotanical samples have been taken and therefore this project aims to clarify the agricultural evidence from these sites. At present, two other sites, Senuwar (Singh 2004, Saraswat 2004) and Lahuradewa (Tewari et al. 2002-2003), have these deposits and they have been sampled for archaeobotanical remains. A table of all the published archaeobotanical remains in the Ganges Valley and Orissa can be seen in appendix 4.1. They both present similar evidence of rice being present from the beginning of the deposits. At Lahuradewa, cultivated rice and wild rice (*Oryza rufipogon*) were identified (Tewari et al. 2002-2003) but there are issues concerning the accurate identification of rice species therefore definite identifications of either species can not be confirmed. In this case, only very few rice grains are present in the lowest levels and it has not been stated the amount found at Senuwar but both are present along with *Setaria glauca* (it can also be called *Setaria pumila* and there are still some identification concerns with this species). Rice husk impressions are found in pottery and mud clods at both sites. At Senuwar, *Coix lachrymal jobi* was also present in the lowest levels. Both of these species are common weeds of rice fields and also occur in the local area today (Saraswat 2004: 490). As is pointed out by Saraswat (2004:490), when referring to Senuwar, it is clear that rice cultivation was a method known to the settlers of the site when they first arrived. However, he also suggests that Koldihwa, Lahuradewa, and Malhar show earlier evidence from 6^{th} – 5^{th} millennium BC (Saraswat 2004: 533-535), which is suggested here to in fact be a similar age or more likely slightly earlier than the deposits found at Senuwar. This phase at Senuwar dates to about 2200 BC (Singh 2004). This rice cultivation could well be of wild rice because at present the problems with identifying rice to species hinder accurate identification and this is something that will be addressed in detail later in this thesis.

The artefactual evidence from these sites (Lahuradewa and Koldihwa/Mahagara) also suggests that the initial phase is of a similar age to that found at Senuwar. This evidence again demonstrates well-developed 'Neolithic' communities containing developed pottery industries, some stone tools including microliths, polished celts, querns and mullers, and also bone tools. There is some evidence of structures in these initial phases such as post holes and burnt clay lumps thought to suggest wattle and daub housing. Cord impressed ware is present at all of the sites and contributes the majority of the pottery assemblage at Koldihwa. Senuwar is dominated by coarse red ware with some corded ware. Lahuradewa also has some corded ware but is dominated by a coarse fabric red ware and coarse black and red ware, which has been suggested as the first development of the later fine fabric black and red ware found in the region (Tewari et al. 2002-2003). Domestic animals are present at all of these sites (except for Lahuradewa) in this initial phase. All this evidence points to a developed society that settled with many of the common elements found in 'Neolithic' communities. Rice cultivation (whether of wild or domestic rice) and the rearing of domestic animals seem to be a known skill of these groups when they settled at the sites. However, at this stage the settlement could still be seasonal to coincide with the rice cultivation and harvesting because there are not extensive structural remains although the excavators suggest these are fully settled sites.

It can not be seen that this small number of sites were in complete isolation since there is evidence to suggest that other sites may contain the same phase but have not been excavated as completely so do not give such full evidence. This is especially true of archaeobotanical evidence because there are no other remains apart from husk and straw impressions in pottery. These sites are either not as large or not as well preserved as the sites already discussed above. The lack of clear dating is also an issue with these related sites.

The discovery of a number of sites around Senuwar is a good example of this. During the investigation of this area a number of sites were found as well as Senuwar: Sakas, Malaon, Badalgarh, Daindih, Akorhi (Singh 2004). The first three of the sites were found in the foothills and the others in the plain along with Senuwar. All the sites are thought to have similar phases and material cultures to those found at Senuwar. Malaon and Badalgarh were particularly badly preserved. Singh (2004: 6-7) has suggested Senuwar was the "parent" settlement because it is larger and located in the middle of all of these related sites. However, no excavations have been reported of these sites and if this was done it may reveal more information concerning the development of this group of sites that is not currently known.

A number of other sites may also possibly have similar early deposits and only through archaeobotanical investigation will it be known if it is the same initial phase because many of the same artefacts continue to the next phase. Bhunadih (Singh & Singh 1997-1998) is located to the east of Lahuradewa and has cord impressed red ware and plain red ware in its initial phase. However, the excavator compares it to pottery from Imlidih-Khurd (Saraswat 1992-1993, Singh 1992-1993), which does not show this initial phase but a slightly more developed first agricultural phase. Again, this has only been separated by archaeobotanical evidence, which is not available from Bhunadih. Moving further east the sites of Taradih (IAR 1985-1986) and Pandu Rajar Dhibi (IAR 1984-1985) also show artefactual evidence but have no archaeobotanical evidence for this initial phase. Further archaeobotanical studies are definitely needed to confirm how widespread this rice agriculture phase is in the region.

During the Neolithic phase at Lahuradewa (1B) and Senuwar (1) there is a considerable change in the agricultural base of the sites. This phase occurs at both sites at approximately 2200-2100 BC. Winter cereals and pulses appear during this phase but there is no significant change in the artefactual evidence. At Lahuradewa, barley is present and at Senuwar, wheat, barley, and lentils are present in this phase. Dish-on-stand pottery forms are found at Lahuradewa implying diffusion from the Harappan region. This is a significant change in subsistence and shows an expansion of the agricultural system and a likely intensification of production. This is the first definite evidence of the cultivation of domestic crops in this region as all of the introductions are non-local and must be domesticates. It also implies an adopted agricultural regime into a pre-existing indigenous cultivation system.

This change in subsistence may also suggest a change in the length of settlement at the site because a double cropping system would require year round occupation or the majority of the year settled in one place. These new crops are likely to come from the Harappan civilisation in Northwest India and it has been suggested that they were brought by migrating people because at this time the Harappan civilisation was collapsing (Saraswat 2004). However, these crops had already diffused in to the Upper Ganges and Haryana sites by pre-Harappan times (3000-2500 BC). Diffusion of this new crop package may have occurred instead of the migration of new people in to the sites because there is no evidence of other new remains, which would be expected with a new population. These crops also appeared in a piecemeal fashion, the earliest being at Damdama, then Lahuradewa, and then further east, which again points to diffusion rather than immigration. In addition to winter crops, more summer crops appear that are not local to these locations, such as *Macrotyloma uniflorum* and *Vigna* spp, which are likely to come from the Upper Ganges/Himalayan foothills or from South/Southwest India. These new agricultural elements are likely to be found at Koldihwa and Mahagara at a similar time but at present the lack of archaeobotanical investigation hinders this comparison. This is an issue that can hopefully be resolved in this project as previously there was only evidence for wheat and mungbean in the Iron Age phase of Koldihwa (Misra 1977).

Senuwar does demonstrate some subtle differences between the initial Neolithic phase (IA) and the later one (IB). Phase IB has more structural evidence and the introduction of a new type of structure. Circular wattle and daub houses are found in IB along with mud structures, which were not found in IA. The initial phase does not show any plans of houses either but this may be the result of the restricted areas for this phase found during excavations. The evidence in IA consisted of rammed earth floors, post holes, and clay lumps with reed impressions. In phase IB circular and rectangular house plans were found. With the changes in agricultural products, it might be expected that domestic tools would change but there seems to be a continuation in the types found at Senuwar but there is an increase in the numbers found in IB. Pottery types also continue in to Phase IB with some refinement of the fabric. Therefore, this introduction of new structural elements and the increase in structures during phase IB might suggest that there was an increase in the settlement intensity or permanence at Senuwar in this phase. This may mean that the site was finally settled for the whole year rather than seasonally settled, which is supported by the two seasons of cereal cultivation. However, there is still no definitive evidence for this and more work is needed on the early settlement of these sites to fully understand what this change in subsistence meant to the people of the Ganges Valley.

There are a number of other sites that show Neolithic artefacts along with the same summer and winter crop package but these are found in the initial phase of the sites. Imlidih-Khurd (Saraswat 1992-1993, Singh 1992-1993) is located just west of Lahuradewa and demonstrates clear evidence of this phase with rice and winter crops present. The initial phases of Malhar (Tewari et al. 1999-2000, 2003-2004a, 2003-2004b), Tokwa (Misra et al. 2000-2001), Waina (IAR 1994-1995, Saraswat 2004-2005), and Chirand (Varma 1971, Vishnu-Mittre 1972, IAR 1981-82) also demonstrate similar evidence. Again, there are some sites that do not have archaeobotanical evidence or any radiocarbon dates and therefore can not clearly be placed within either part of the Neolithic but have been suggested to be similar to the deposits of the above sites. These sites include Chechar-Kutubpur (IAR 1977-78), Maner (IAR 1989-90), and the previously mentioned sites of Taradih, Bhunadih, and Pandu Rajar Dhibi.

Chalcolithic deposits are found in all of the sites mentioned with Neolithic deposits. Singh (2004: xiii) suggests that this phase is found at all sites in Bihar and dates to approximately between 1950 and 1300 BC. This period may appear later at some sites and lasts until 700 BC. This phase is characterised by the addition of copper and a refinement of earlier material. Pottery is a particularly important feature of this region at this time and shows that the majority of sites had some sort of link whether just trade or they may have had some sort of cultural affinity. Painted black slipped ware and painted black and red ware is common on most of these sites, although other earlier pottery types continue. Painting is usually in white and sometimes black or ochre pigment. Linear designs are common but cord-impressed patterns also continue at most sites. Copper objects such as fish hooks, rods, and nail cutters are present. There is much clearer evidence of structures in this period with post holes, rammed earth floors, mud walls, and circular house plans being common. Grain bins are found at Lahuradewa, Agiabar (Singh & Singh 1999-2000), and Waina, which may suggest another intensification of production in the ability to produce a larger surplus perhaps to support increased trade or craft specialists.

The site of Narhan (Singh 1994) gives it name to the culture of this period (the Narhan culture) and elements of this culture can be seen at the majority of sites in the Ganges region. The main feature of the culture is the white painted black and red ware pottery and also black slipped ware is painted occasionally in phase one but becomes the dominant ware in the second phase of the site. Narhan is located on the left bank of the River Ghaghara, in Gorakhpur district, Uttar Pradesh. The site has two ancient occupation mounds. Mound one is fairly flat and is partially occupied by the present village of Narhan and also some of the site is under cultivation. A major part of mound one has been swept away by the River, which lies directly on its south-western side. Mound two is to the northeast of the modern village and is about 300 sq metres in area. It rises to a height of

5.50m and has also been disturbed by agriculture and brick robbing, which has affected the upper 1.35m of deposits. Both mounds have been subjected to excavation and five cultural phases were found. The first two periods are the most important for issues of early agricultural development and show Chalcolithic and Iron Age deposits. The typical Narhan culture is found in phase one of the site and has the white painted pottery as well as plain and slipped red ware. The black and red ware is found as bowls, basins, and vases. There is evidence of structures including post holes, reed impressed clay lumps, hearths, and rammed earth floors. Other artefacts include pottery discs, bone points, and one polished stone axe. Two iron objects were found in the upper deposits of this phase. Domestic animals (humped cattle, sheep/goat), wild antelope and horse were all found. Fish was also exploited as a foodstuff. Plant remains are rich right from the beginning of the deposits and contain rice as well as wheat, barley, winter pulses, and some of the native Indian pulses. This represents a well developed agricultural system and suggests a double cropping system. These deposits are thought to date from 1300 BC to 700 BC.

As well as Narhan there are a number of sites that appear in the Chalcolithic. The sites of Khairadih (Singh 1987-88), Manjhi (IAR 1983-84, Chanchala 2000-2001), and Agiabar (Singh & Singh 1999-2000) all appear with the characteristic Narhan painted pottery as well as the other aspects of this period. By this time there were a large number of agricultural sites established in Uttar Pradesh and Bihar. From the current archaeobotanical evidence it seems that the sites all have similar economic systems including well-developed double cropping agricultural systems and they were also raising domestic animals. The sites were all settled year round by the late Neolithic/Chalcolithic period. A well developed pottery industry was present from the beginning of the Neolithic and continued to be refined in to the Chalcolithic period displaying similar cultural elements throughout the region. Whether there is a similar pattern of growth in Orissa will be discussed below.

4.2 Early farming settlements in Orissa

Orissa is one of the most poorly studied areas of India in terms of archaeological investigations and in particular agricultural development. Few excavations have taken place in this state and there is a complete lack of archaeobotanical sampling and flotation. This is not the result of a deficiency in archaeological remains as Orissa appears to have abundant archaeological sites of all periods (Basa & Mohanty 2000, Sengupta & Panja 2002) and therefore offers the potential for new investigations in to the prehistory of this area.

Studies of prehistory in Orissa began in 1876 when V Ball (Ball 1876) found four Palaeoliths in Angul, Talcher, Dhenkanal, and Bursapalli. It took until the 1930's for the first explorations to begin with Paramanansa Acharya and a Harvard University researcher, E C Worman. They explored the lower Palaeolithic site of Kuliana in Mayurbhanj, which was later excavated by N K Bose and D Sen (1948) of Calcutta University. More surveys were conducted by Calcutta University in 1950's. The first Neolithic site to be excavated was Kuchai in Mayurbhanj, during the 1960's (IAR 1961-62: 36). However, it was not until the 1980's that more widespread surveys were conducted and a growing knowledge of the Stone Age became clear for the whole state of Orissa (Basa 2000: 38).

It is clear that there are differences between the prehistoric sites in different parts of the state, which may be due to their geographic positions however, it is best to work through the sites and types of sites chronologically (see figure 4.5 for a map of the sites mentioned in the text from Orissa). Prehistoric settlements in the coastal plain and riverine areas of Orissa seem to have been established by the 3rd millennium BC and are located close to Chilka Lake and the Mahanadi delta, which feeds in to it (Misra 2002). These sites are substantial mounds with continuous sequences of deposits from the Neolithic through to the Iron Age (1st millennium BC). A number of these sites have been explored: Golbai Sasan (Sinha 1993, 2000, Mohanty 1994), Gopalpur (Kar 1995, 2000, Kar et al. 1998), and

Khameswaripalli (Behera 2002). At the later site, the excavators have not defined a Neolithic phase and therefore the site starts at a so called Chalcolithic phase. This will be discussed in more detail below. There are a few other riverine sites that have been defined as Chalcolithic and have similar artefacts to the multi-phased sites; Bhejidihi in Angul district and Kurmigudi in Sambalpur district. These sites all seem to have similar Chalcolithic and Iron Age phases, which will be discussed below. The fact that these sites are all close to rivers and generally multi-phased is similar to the sites in the Ganges Valley discussed above.

In contrast to these mounded sites are highland sites, which appear to be more ephemeral and therefore do not have the depth of deposits found in the coastal lowlands. Some highland sites near to Chilka Lake have been suggested as Mesolithic hunter-gatherer sites from microlithic finds, which may represent the people who later moved to the lowland sedentary sites (Misra 2002). However in North Orissa, these ephemeral sites are probably more contemporaneous with the settled farming societies in the lowlands especially the earlier Neolithic deposits and may therefore represent a subsistence choice of shifting cultivation or more mobile peoples with seasonal camps. Shifting cultivators still exist today in the North Orissan Highlands and areas of adjacent states (Mohanty 1998, Pratap 2000) and therefore suggests a potentially different pathway for prehistoric people to the settled life of the lowlands. Hence, two different trajectories may be apparent at the same time in Orissa: a move to settled agricultural life in the lowlands and a more mobile life incorporating shifting cultivation or seasonal cultivation in the highlands.

If the sites are examined chronologically, then the pattern stated above becomes more complex. Characteristic artefacts of the Neolithic industry in Orissa are axes, adzes, chisels, bar celts, scrapers, ring stones, shoulder celts, and pottery (Mohanty 1992, Mohanta 2000).

Heavy stone artefacts are also present such as pounders and grinding stones. Dash (1987, 2000) has conducted a lithic study on Neolithic material resulting in the suggestion of five stages of lithic development in Orissa: i) elongated and bigger oblong types, ii) fine oval and egg shaped tools, iii) triangular types with rounded corners and cylindrical types, iv) quadrangular forms without corner edges, v) purely quadrangular and faceted forms. However it must be remembered that this study was conducted wholly on surface collections (Basa 1997). Lithic remains are not always present in Neolithic deposits and neither is pottery therefore the type of site seems to be important for the choice of material culture. Botanical evidence is rare and has only been reported as impressions in pottery but this is likely to be due to the lack of systematic environmental sampling at all of the sites in question.

Golbai Sasan is the most extensively excavated of the mounded sites and therefore offers the best evidence of early farming settlements in this area (Sinha 1993, 2000, Mohanty 1994). The site is located on the left bank of the river Mandakini, a tributary of the Daya River, which flows in to Chilka Lake. The excavators have recognised three distinct periods: Neolithic, Chalcolithic, and Iron Age. The Neolithic period at this site is one of only two excavated Neolithic deposits in Orissa. The other is in Kuchai (Thapar 1961-62, Basa 1997) in Mayurbhanj, northern Orissa, which is discussed below. The Neolithic deposits at Golbai Sasan cover only a small area of the excavations. There are five layers giving a total depth of just over 1 metre of deposits (Sinha 2000). No clear structures were found but post holes and what is thought to be a floor level of rammed clay was discovered. No stone tools were found but there were some worked bone tools. The pottery present was mostly handmade and only some sherds appeared to be wheelmade. Two wares were found: dull red and grey wares. The grey wares sometimes had chocolate coloured slips or washes. Some of the pottery has paintings in red ochre and cord or reed impressions. The shapes present were bowls, vases, and pot stands. There is no faunal or floral evidence reported from this phase of the site but no environmental sampling was conducted during the excavations. It is interesting that this site does not have any of the characteristic stone tools that are found on other Neolithic sites. This may be due to only a small area being discovered or could suggest these people relied on other materials to make tools such as the bone tools found. This site was chosen to be systematically sampled for environmental remains because it has considerable depth of deposits and therefore is likely to have a build up of organic debris including macro-botanical remains and phytoliths.

Gopalpur has not been excavated but from surface collection is thought to have an affinity with Golbai Sasan and is suggested to have a Neolithic phase (Kar 1995-1996, 2000, Kar et al. 1998,) Similar Neolithic pottery types have been found: dull red and grey ware. It is not clear what of the other evidence collected from this site comes from this earliest phase such as the celts that were found and therefore these artefacts will be discussed in the section on Chalcolithic deposits. This site was also chosen for systematic sampling to recover archaeobotanical remains for investigation in this project.

Kuchai, the other excavated site, does not appear to have the same depth of deposits as Golbai Sasan but does have some similar remains. The site is located 8 km from Baripada, northern Orissa and 6 km east of Burhabalang River. Excavations took place in the 1960s to a depth of 1.40m (Thapar 1961-62, 1985). Neolithic deposits are approximately 40 cm deep with a total depth of all occupation deposits reaching about 75 cm. Red ware pottery was found, which was tempered with a coarse grit. This was sometimes slipped and incised or decorated with finger-tips. An orange-brown ware was also found. Some of the pottery has been reported to have wild rice impressions (Vishnu-Mittre 1976). Unlike Golbai Sasan, Kuchai does have stone tools from this period which are all of butt-end variety: butt-ended axes, faceted hoes, chisels, maceheads, pounders, and grinding stones. Below the Neolithic deposit is a Mesolithic layer. This is the earliest layer on the site and consists of gravel mixed with greyish earth and loose laterite. There is no pottery in this layer but it contains non-geometric microliths. This site was visited during the 2003 field season but was found to have been destroyed by modern agricultural activities and therefore no samples were taken.

The nearby site of Baidyapur, which lies 16 km south of the Burhabalang River, shows similar pottery wares to Kuchai. Handmade coarse red ware was present along with one fragment of fine red slipped ware, which was possibly a cooking vessel. Husks of domestic rice have been reported from this site (Vishnu-Mittre 1974). The exploitation of wild rice for pottery temper at Kuchai and possible domestic rice at Baidyapur is interesting and may suggest rice, whether "wild" or "domestic", as a foodstuff because of the presence of grinding stones at Kuchai.

The deposits from Kuchai and Golbai Sasan are quite different. They do have similar coarse red wares but also have other different pottery wares. The presence of stone tools at Kuchai is in contrast to the lack of stone tools at Golbai Sasan although this site contains bone tools. These differences may be expected because of their different locations and may be the result of availability and exploitation of resources. They demonstrate two different Neolithic traditions existing in Orissa.

A survey of Neolithic sites in northern Orissa has been conducted by Mohanta (2002). Thirty nine sites were discovered based on large collections of surface finds being found. Eight of the sites were at foothills, eight at piedmont but the majority were found on river banks. This may be because it is generally easier to field walk along the edge of rivers and therefore there is more chance of discovering sites in these particular locations. However, it is interesting that there are a lot of sites along river banks and this shows similarity with other areas in Orissa. The majority of sites found in Mohanta's study lacked any stratigraphy. Most were large scatters of lithic material. Ceramics were rarely found on these sites and no plant remains were recovered.

An example of one of these sites is Banabasa. The site is a small hillock close to the left bank of the river Khairi in Mayurbhanj, North Orissa. There are three distinct locations at the site covering an area of 125 x 27 square metres. Banabasa 3 is in the piedmont area and Banabasa 1 and 2 are on the banks of the river. Banabasa 2 was sampled for environmental remains in this project because it was thought to have the greatest depth of deposit: up to 50cm at the most. Sampling of this site is discussed in chapter 5. There was no stratigraphy seen during sampling and no clear evidence of occupation material such as charcoal or pottery. Lithic scatters were the only material found, but not in the trench, just on the surface including axe, adze, broken celt, chopper, chisel, ringstone, hammer stone, and microliths.

Mohanta (2002: 186) comments that these northern Neolithic sites have similar lithic remains to those found at Sulabhdihi in the Sundargarh district of Orissa (Behera 1991-1992, 1992, 2000). Sulabhdihi has been interpreted as a mass production site for semi-finished celts. It consists of 4 large debris mounds entirely made of dolerite debris. All stages of the manufacturing process are represented apart from the latter stages. As well as this site there is a whole complex of pebble tool sites in this area (Behera 1992). They are known as the Bonaigarh Neolithic complex. This consists of a set of pebble tools: bored pebbles, chopper-chopping tools, unifacially flaked pebbles, waisted flat pebbles, worked split pebbles, worked elongated pebbles, elongated knives and grain pounders. Behera (1992: 62) suggests that such a broad spectrum of pebble tools are needed to exist in the forests of this region.

More Neolithic sites have been found in Pallahara in Angul district, central Orissa. 16 prehistoric sites have been discovered of which nine contained Neoliths (Basa et al

2000, Mohanta 2002). The remains found were axes, chisels, flakes, and chips. Two celt manufacturing sites were located, one close to Pallahara college and the other at Bajpur. The difference of these sites to the other lithic scatter sites is that they also contain pottery. Trial trenches have been excavated at Bajpur.

Bajpur is situated on the left hand side of the National Highway 6 towards Keonjhar and 1km away from Pallahara College. The site area is about 200 sq. m and contains surface finds of finished and unfinished stone tools and pottery sherds. Previous trial trenches revealed little organic remains except a small amount of charcoal. Lithics were recovered as well as red ware pottery some with red slip. The site consists of three layers with a total depth of approximately 0.85 m. There are two Neolithic levels preceded by a lower Mesolithic level. This site has been sampled in this project. Environmental samples were taken from an area not under cultivation down to 50cm and therefore we have sampled down to the Mesolithic deposit. Unfortunately, rice cultivation has encroached on the site and much is now under cultivation including the central part of the site where these earlier observations were made. This means that the new trial trench is probably not in the richest part of the site and therefore may not reflect what has been found previously.

The nearby site of Kamparkala on the right bank of the Kakharua River was previously trial trenched and revealed a large amount of lithics and pottery (Mohanta 2002: 12). The lithics present were flakes, blades, chips, chisels, points, ringstones, fluted cores, end scrapers, discs, axes, and lunates. Red ware pottery was also found most of which was body sherds and was a medium to coarse texture. These remains are similar to those found at Bajpur. There were also other Neolithic sites around this area where similar lithics were collected.

Another survey has been conducted in the area of Darpankhas, Jajpur district, coastal Orissa (Sahoo 2000, Sahoo & Tripathy 1988-89). The majority of sites found contained Mesolithic lithics, but five sites had Neolithic remains. They contained a small amount of lithics and these were a wide variety of types. Ground axes, chipped axes, adzes, chisels, shouldered axes, ringstones, and arrowheads were present.

The evidence for the Neolithic phase in Orissa demonstrates geographic differences in the material remains and also shows that more large-scale excavations are needed to fully understand this period. A single TL date has been taken from the final phase at Kuchai of 1000 BC but this seems rather late for Neolithic deposits and can be considered as *terminus ante quem*. There is no other dating evidence for any of the sites but a date of the 3rd millennium BC seems plausible from current Chalcolithic dates. It is clear that radiocarbon dates are needed to confirm the age of this phase throughout the state. Large excavations have only taken place at Golbai Sasan and Kuchai, which have not clearly shown evidence of permanent settlement although post holes and a possible floor were present at the former site. Red ware pottery, mostly with a coarse fabric, seems to be consistent throughout the state. Other pottery wares are also present at some sites. The lithic remains found in northern and central Orissa are similar. The large scatters of material seem to occur on areas with little evidence for settlement. These sites have very little or no stratigraphy and in the majority of cases lack pottery. The majority of these sites are probably specialised lithic working sites such has been suggested by Behera (2000) for Sulabhdihi. However, some of the sites such as Bajpur and certainly Kuchai are more likely to be occupation sites. The lack of buildings and shallowness of deposits suggests that occupation in these places may have been short lived or seasonal. Kuchai and Baidyapur have the only economic evidence suggesting the use of wild and possibly domestic rice. Golbai Sasan and Gopalpur demonstrate a different Neolithic phase to that found at the northern and central sites. There are no lithics in the Neolithic phases of Golbai Sasan, while Gopalpur has celts present although these may come from later phases. Both sites have the distinctive red ware pottery. Bone tools seem to play a significant part in the material culture of these sites. This difference in material culture may relate to the activities of these prehistoric peoples. It has been suggested that a large variety of stone tools relates to the exploitation of forest products such as hunting and gathering or shifting cultivation (Behera 1992). The coastal or riverine sites of Golbai Sasan and Gopalpur have this different tool assemblage and therefore may rely on a different subsistence strategy in this phase such as fishing and wetland agriculture.

More Chalcolithic sites have been excavated than Neolithic sites and therefore it is slightly easier to try to define this phase in Orissa. The Chalcolithic phase in Orissa is recognised by having many of the same elements as the previous Neolithic period but with the addition of copper objects and new pottery wares such as black and red ware. This period seems to continue at most sites into what has been termed the Ferro-Chalcolithic phase, which has the addition of iron objects with many of the Chalcolithic elements persisting. This phase would be termed Iron Age in most other regions of India.

Once more, Golbai Sasan is the most extensively excavated site of the phase. This site has the only recorded radiocarbon dates (IAR 1993-1994) for the coastal sites. Four dates have been reported and they are rather confusing. Layer 13, at a depth of 3.9m, is the beginning of the Chalcolithic deposits, which is dated to 4100 ± 100 BP (PRL 1637) however, layer 4 at a depth of 1.55m is dated to 4310 ± 100 BP (PRL 1642). There are also two other dates that are 2600 ± 90 BP (PRL 1641), which is a Chalcolithic deposit at 2.4m and then 2710 ± 90 BP (PRL 1646), which is from Neolithic deposit at 4.65m. It is clear that this is all very contradictory and hard to interpret. The excavators have taken the date from the lowest level of Chalcolithic deposits as a true date but it is hard to accept any of the dates. Old wood residuality and mixing of deposits overall are processes that also need to be considered. It is clear that further dating is needed to clarify the situation.

At Golbai Sasan, the excavators have suggested an influx of people on to the site at the start of this period because new technologies are found, such as stone tools, copper tools, and different pottery wares (Sinha 1993, 2000). These deposits are substantially larger than the Neolithic phase of this site and may suggest that this site is now settled year round but more work on the Neolithic phase is needed before this can be confirmed. The Chalcolithic deposits consist of ten layers and over five metres of deposits. In the lower levels of the Chalcolithic phase at the site, there is clear evidence of circular huts with post holes and hearths. Thirteen huts of different sizes are present with floors of rammed red clay. In an upper level of this period an extended female child burial was found that contained copper bangles and the head was severed. Bone tools were an important part of the material culture and they made up approximately 75% of all artefacts. There was a wide variety of bone tools including spearheads, points, burins, diggers, blades, adzes, pick axes, and chisels. These tools could be used for many purposes such as hunting and fishing, domestic use, and digging. The lithic remains added to the tool assemblage with celts, adzes, chisels, polishers, querns, shouldered celts, and knife blades. Copper tools were also found including chisels and fish hooks. Terracotta human figurines and faience objects were present.

Pottery from Golbai Sasan was predominantly wheel made with red burnished slip ware, dull red ware, black slipped or burnished ware, black and red ware, buff ware, grey ware, and chocolate ware. These could be painted (in red ochre), or incised. Most types were of fine to medium texture fabrics. Common shapes include vases, bowls, lids, jars, dishes and dishes on stands. Some very small pots were present, which may have been used as crucibles.

Charred grains of rice and horsegram were found during the excavations but no systematic environmental sampling took place. The remains of domestic cattle, sheep, and goat were found along with wild animals such as elephant, deer, bear, antelope and fish. Sea fish and river fish remains were present. Therefore, the economy of this site is based on some agriculture (the full extent of which is not known at present), raising animals, hunting of animals, and fishing.

The next phase at this site has been termed Ferro-Chalcolithic because it sees the addition of iron objects (Sinha 2000). Much of the same artefacts are found in this phase as the one before and there is no break in the deposits between the two phases. There are no clear hut plans in these layers but floor levels and post holes are present. Black and red ware pottery in this phase is of a rough texture compared to the earlier phase and two new shapes appear: tumbler and a convex sided bowl.

There are a number of other sites that have similar evidence to Golbai Sasan and they are thought to be associated with the site. They are all large mounds with substantial occupation deposits. The sites also tend to be close to rivers, if not right on a river bank. Gopalpur is geographically the closest site to Golbai Sasan that has been explored (Kar 1995-1996, 2000, Kar et al. 1998). The site is located 72 km south of Bhubaneswar, in Nayagarh District. There is a stream, Khatiari, which cuts through the mound exposing a clear section. From surface explorations at Gopalpur, similar pottery to that found at Golbai Sasan was recovered including the earlier red and grey wares, and the subsequent black and red wares associated with the Chalcolithic. Other types present are red slipped ware, dull red ware, cream slipped ware, chocolate ware, and burnished black ware. None of the pottery has been painted but decoration occurs in the form of incised and appliqué designs. Two types of stone tools were found: celts and larger domestic tools. The larger celts are triangular and the smaller celts are trapezoid and flat. The domestic stone tools found are rubbing stones, querns, pestles, and perforated stones. No metal objects were found during the exploration but villagers have reported finding copper and iron objects in the river bed and on the surface of the site (Kar 2000: 375). There is less evidence of a rich bone tool industry but bones of domestic animals (cattle and buffalo) as well as wild animals (nilgai, chital, wild pig and rhino) were found (Kar et al. 1998). No plant remains have been reported from Gopalpur and therefore from previous work implications can not be made concerning the agricultural activities of these people.

The site of Khameswaripali is located 12km east of Sonepur town in Subarnapur district (Behera 2000-2001, 2002). This is in the Middle Mahanadi Valley. The site lies on the left bank of the Mahanadi River and rises seven metres above it. The site area is about 130 m in length and 80 m wide. Three trenches have been excavated at this site; one on the highest part of the site (3m x 3m) and two on moderate slopes at the sides of the site (3m x 3m and 2.50m x 2m). The excavation went down to natural soil and habitational deposits range from 2.20m to 1.40m. The excavators found three cultural phases but split phase one in to two parts. No radiocarbon dates have been reported from this site but the excavators suggest that the site dates between the late 3rd millennium BC and the early 2nd millennium BC. Phase IA overlaid the natural soil and was 0.65-0.75m thick. There were no clear structures found but burnt clay lumps with reed impressions were present, which have been interpreted as evidence of wattle and daub houses. The pottery was wheelmade and had four main types: plain and painted black and red ware, burnished black/dark grey ware, red slipped ware, and plain red ware. Black and red ware was the dominant type, which was sometimes slipped and burnished. Dishes and large vessels were absent in this phase but bowls, small vases, and basins were present. An interesting aspect of the pottery assemblage is bowls and vases painted with white pigment, usually in lines or zigzag motifs. This resembles the pottery of the Narhan culture found in the Ganges Valley and might suggest the excavators dating is too early as the Narhan culture is not established until about 1300 BC. It would be interesting to collect environmental samples from this site to see if it also has the economic features of the Narhan culture, especially the winter crops. However, this has not been possible in this project.

The plain red ware, found at Khameswaripali, is also interesting because it is coarse as in the Neolithic sites previously discussed. This ware was present as vases, handis (cooking vessels), pots with ring bases, bowls, perforated bases, basins, shallow bowls on stand and lids with handles. Some of these vessels have cord impressions. Other artefacts found are bone tools, beads, pottery discs, small axes, and a few microliths. No copper objects are found in this phase. No environmental sampling took place during these excavations but there is some idea of the economy from animal bones found. These were domestic animals such as cattle, buffalo, sheep/goat, and wild animals such as wild boar, wild ungulates, and molluscs. Impressions of rice and millets were found on clay lumps and may also suggest some agriculture. However, the excavator has suggested only a small level of agriculture due to the lack of large storage vessels. Crops do not always have to be stored in this way so this is not necessarily true. It is only really with systematic environmental sampling that this question can be answered.

Phase IB has deposits between 0.30 to 0.50m thick. There is clear evidence of structures in this phase. A portion of a stone circle was found with a mud wall on top. There were also post holes near this structure. Pottery wares continued from the previous phase with the addition of black slipped ware. New objects found were bone points, possible ivory bangles, terracotta beads, and stone pestles. This phase is thought to also have the same economy as IA. These two part phases are definitely related and have probably been separated because of the capping layer above IA and the structures and new artefacts in IB.

It is interesting that these phase I deposits do not have copper and if there was not such a developed pottery assemblage then this phase would probably be called Neolithic.

In phase II, copper objects are found and the pottery assemblage deteriorates. Deposits for this phase are 0.30 to 0.50m thick. There is no evidence for structures except for burnt mud brick. The majority of materials continue from the previous phase but there is less burnishing and white slip on pottery, and plain red ware is dominant. Dishes and storages vessels appear in this phase.

The third phase has the addition of iron and there are further changes in the pottery assemblage. Grit tempered red ware is dominant, some with red slip. There are lots of different shapes including large sized vessels. Beads, glass bangles, copper rings, pottery discs, and cowri shells are present. This phase has some of the early elements found at the nearby early historic site of Manamunda (IAR 1989-1990).

Another riverine Chalcolithic site is Bhejidihi, situated on the left bank of the San-Karandi River north of Bhejidihi village in Angul district (Pradhan 2002). The site measures 150m by 120m. Two trenches of 3m x 3m were excavated exposing five occupation layers. These were split in to two phase: I.) Chalcolithic and II.) Iron Age. The Chalcolithic phase resembles somewhat the remains from phase II at Khameswaripali. Red ware pottery is dominant but red slipped ware, black ware, black slipped ware, and black and red ware are also present. The red ware is of a coarse to fine texture with a coarse sand temper. Some of the sherds are painted with black wavy lines. Other artefacts are stone celts, bladelets, fluted cores, beads, bone points, and copper ingots with a crucible.

Kurmigudi also has similar remains to Khameswaripali and Bhejidihi (Pradhan 2002). This is another mound site that lies on the left bank of Karandi jor, a tributary of the Mahanadi River. It is situated 0.5 km to the west of the village Pankhimal, in Sambalpur district. The site is 115m by 75m and a trial trench (2m x 2m) has revealed two occupation layers both Chalcolithic. There was a large amount of pottery, which was similar to the wares found at Bhejidihi except that no painted pottery was found. Red ware, with a coarse fabric, was the dominant type in both layers. Other artefacts include stone celts, fluted cores, bladelets, ring stones, bone points, crucibles, and worked antlers.

All of the above Chalcolithic sites are situated in coastal Orissa or the middle Mahanadi River valley close to river banks. They are substantial mounds with most of the sites being multi-phased with thick deposits. This means that they are sedentary long-lived sites. Bone tools are of clear importance at these sites and probably relate to a routine activity performed by all of these sites such as fishing and agriculture. Stone tools do not seem to play such a large role with celts and domestic stone objects such as grinding stones being the most common. Copper objects are also found but appear in small numbers. Pottery is well developed at these sites with some hand made vessels but the majority are wheel made. Coarse red ware seems to appear consistently at all of the sites. Black and red ware is also present at all of the sites and has some interesting variations such as the white painted designs at Khameswaripali, which resembles that of the Narhan culture pottery.

In Northern and Central parts of Orissa state, there are more Chalcolithic sites although they differ in size compared to the sites of the Coastal and Middle Mahanadi River valley tending not to have as substantial deposits. Sankerjang is a group of mounds located in Angul district, Central Orissa (Yule et al. 1989, 1990, Yule & Rath 2000). This site covers approximately 500 square metres and is a cemetery site. During excavations three layers were found. The upper two layers were sterile but the third contained a large number of stone and copper artefacts as well as nine burials. The lithics present were axes, adzes, chisels, shouldered celts and ringstones. Copper bangles and celts were found. The skeletal remains included five children and four adults. Handmade pottery was also present although it is not mentioned what type was present. A radiocarbon date has been published from this site, 2590 ± 60 BP (KH 3755), which was the first reported date for Orissa (Basa 1994: 12-13).

In Northern Orissa, there are two known Chalcolithic sites: Baghada and Kuanr. Ten copper double axes were found accidentally at Baghada, 30cm beneath the surface (Cobden-Ramsey 1916: 336-337). The actual site lies 1km west of the village of Baghada, on both river banks of the Gulpha River. Section scrapings have been conducted to assess the stratigraphy of the site and revealed about 80 cm of deposits in six layers therefore the occupation deposits are fairly shallow. Layers three, four, and five contained artefacts including red ware pottery and unidentified objects.

Trial trenches have been excavated at Kuanr (Ray et al. 2000). The site is located on top of a mound, on the right bank of a tributary called Masani nallah, in Kanjipani area of Keojhar district. The site lies under forest cover. The mound is kidney shaped and approximately 196 m long. The artefacts were found just below the top soil on top of a layer of reddish brown soil. The stratigraphy was fairly shallow and there was no evidence of structures. The test pits revealed a large amount of artefacts including lithics, pottery, and metal objects. A wide range of lithics were present such as axe, adze, saddle-quern, ring-stone, hammer stone, scrapers, blades, points, awls, borers, knives, flakes, and chips. These were nearly all made of basalt. The celts made by chipping, pecking, and grinding techniques; polishing was only used on one tool. Potsherds were fragmentary with red and buff wares found. Some of the pottery was slipped and had a coarse to medium fabric with grit temper. Husk and straw temper was present in some of the sherds. Nine bangles and two rings were found and they were made of bronze.

There are few excavated Chalcolithic sites in Central and Northern areas of Orissa. However, similarities and differences to the Coastal and Riverine sites can be assessed. The central and northern sites have shallower deposits especially if they are compared to Golbai Sasan. There is no structural evidence from any of these sites and it could therefore be suggested that none of these sites represent long term occupation sites. Similar lithic and metal remains are present on all of the sites. Red ware pottery is present at Kuanr much like at the coastal sites. There is a complete lack of economic remains and therefore there are no clues to the subsistence of the Chalcolithic people of central and northern Orissa.

Overall, evidence is still limited for the Neolithic and Chalcolithic periods of Orissa and particularly evidence for the development of farming societies. This is due to a lack of large scale excavations and Golbai Sasan is really the only site with clear evidence for all periods. It is also the only site to have a clear stratigraphic sequence of lithics, pottery, and metal objects. There is some evidence for subsistence strategies in Orissa from hand-picked finds and pottery inclusions. In the Neolithic phase, wild rice and possible domestic rice has been found in pottery in Northern Orissa. However, there is little structural evidence and therefore year round settlement may not yet be in existence at this time. Therefore, any plant cultivation would have been based around seasonal or short term camps.

In the Chalcolithic phase, there is much more evidence for substantial occupation in the coastal and Middle Mahanadi areas of Orissa and therefore long term and probably year round settlements can be suggested. This may suggest a more settled agriculture regime or even two seasons of crops. Evidence from Golbai Sasan shows remains of rice and horsegram but none of this evidence has come from systematic environmental sampling. Animal bones from the same site have shown evidence for domestic animals and also wild animals. Fish bones and molluscs have been found at some sites as well as fish hooks. This demonstrates a rich economic system. However, the new samples in this project, taken from some of the sites mentioned above, will add a great deal to this rather sketchy outline of the economy that is presently known and start to build a more detailed insight in to what plants were being exploited and also the agricultural regimes practised by the prehistoric people of Orissa.

4.3 Summary of issues

Much more evidence has come from excavations of sites in the Ganges Valley to that currently available from Orissa. This means that a pattern is emerging for the development of agricultural societies in the Ganges Valley but there are still many issues that need clarification such as the initial development of agricultural systems and whether rice was domesticated locally. Very little archaeobotanical evidence comes from the Mesolithic sites in this region but there are some remains of wild rice and other wild grasses, which suggest a gathering economy. There is also some evidence of structures but the deposits are shallow and therefore these sites are likely to be seasonal. The initial phases of the Neolithic demonstrates some evidence of rice exploitation, which may be the cultivation of rice but more studies are needed to confirm this and also whether it is domestic as suggested by the excavators. However, if we assume rice cultivation then this is a known technique from the beginning of these sites therefore these people settled at these locations with previous knowledge of rice exploitation. The settlement at this point may be seasonal because there are not substantial structural deposits however the excavators suggest that they are fully settled sites. At this time there is a developed Neolithic artefact assemblage with cord impressed pottery, and lithics. The next important development is during the later part of the Neolithic, when Southwest Asian crops and more indigenous crops are added to the economy. This demonstrates a significant change in the subsistence pattern of the region but does not coincide with any large change in material culture. This may suggest that the crops came to the sites through diffusion rather than brought by migrating people as has been suggested by some scholars (Saraswat 2004). This is the first definite evidence of the use of domestic crops and plant cultivation in this region. The addition of the new winter crops meant a change to a new double cropping system as well as the extension of existing summer crop species cultivated and this may suggest, along with some changes and increases in structural evidence, that these sites were now occupied all year round.

What this current evidence does not address is the issue of the transition between the earlier Mesolithic sites into the much later Neolithic sites. If the 6th-5th millennium BC dates are ignored from the Neolithic sites then there may be a large gap of time between these two cultures. It has been suggested that Chopani Mando, Koldihwa, and Mahagara may demonstrate a transition from wild to domestic rice. This can be explored in this project as environmental samples have been collected from all of these sites. Whether the rice is wild or domestic is something that needs to be addressed in this project and a thorough review of current identification methods will be conducted along with suggestions of new approaches to this question. The issue of when the Southwest Asian crops arrive at Koldihwa and Mahagara can also be investigated and hopefully a detailed archaeobotanical investigation can give insight in to the agricultural systems at these sites.

It is not clear at present what the economy of the Neolithic or Chalcolithic is in any part of Orissa. Present evidence seems to suggest that permanent settlement did not occur until the Chalcolithic but further investigations are needed in to the Neolithic phase. It will be interesting to find out what crops are present in Orissa and when they start to appear at different sites. Will the Southern Coastal mounded sites present similar economies to the northern and central sites? It may also be possible to establish when agriculture began in different parts of Orissa and whether any elements of the economy are indigenous. The introduction of Southwest Asian crops may also be an issue to consider in Orissa as they had reached Bihar by about 2000 BC but may not come to Orissa until later or may not have arrived at all.

The next chapter gives details of the sites sampled in this project, sets out new dating evidence, and discusses the archaeobotanical methods used both in the field and in the laboratory.

Chapter 5

Methodology: site descriptions, field and laboratory methods.

In this chapter the sites that are sampled in this project will be introduced and the methodologies used for sampling and processing in the field. The techniques used in the laboratory are also described here including processing of phytoliths, identification issues, and analytical methods used on the dataset.

5.1 Field methods

5.1.1 Site selection and sampling in Uttar Pradesh

To address the questions set in this project of examining early farming communities in Northern and Eastern India, a number of different sites need to be sampled. As stated previously, two specific areas have been chosen for focus because they offer a variety of sites, single phased and multi-phased, and highland and lowland sites. In the Belan River Valley, North-Central India, three sites have been sampled; Chopani-Mando (CPM), Koldihwa (KDW), and Mahagara (MGR). CPM, KDW, and MGR were sampled by Dr Dorian Fuller in 2001 by exposing a section in previously excavated trenches. Bulk samples and phytolith samples were taken from each stratigraphic layer according to the excavator's plans (see figures 5.1 – 5.3 for section drawings). The volume of bulk sample extracted from each layer was 20 litres and additionally a small amount of sediment (approximately 100ml) was taken for phytolith samples from the same layers.

Chopani-Mando

Chopani-Mando is situated on the old channel of the river Belan approximately 77km east of Allahabad. The original excavations took place in 1967. The total habitation deposit at Chopani-Mando is 1.55m deep. This comprises of ten layers and archaeobotanical samples have been taken from each one (see figure 5.4 for table of the samples taken). These layers have been divided in to three cultural phases by the original excavators based on lithic tools (Sharma et al. 1980a). Layer 10, at the bottom of the deposits, lies on bedrock and is defined as being from the Epi-Palaeolithic (I). The early Mesolithic is divided in to two sub-phases. The early Mesolithic (IIA), which is composed of non geo-metric microliths, is found in layers 9 and 8. Layer 9 has the first evidence of structures with a number of post-holes present that are dug in to layer 10. Phase IIB, the second early Mesolithic sub-phase, contains geometric lithics. These deposits comprise of layers 7 to 4. These layers contain more evidence of structures again in the form of post-holes in layers 7 and 6. The advanced Mesolithic (phase III), is found in layers 3 to 1. This phase has the first appearance of the handmade pottery and also more evidence of structures in the form of post-holes and hearths. There is only one date available for this site and this is ca. 3500 BC. Unfortunately, there was not enough material recovered in this project to allow new dating at this site.

Koldihwa

Koldihwa is situated on the left bank of the river Belan approximately 85km from Allahabad (Sharma et al. 1980a). One interpretation is that there was originally one mound thought to be 500m by 200m but it eroded in to a number of small mounds (Sharma et al. 1980a). However, it is more likely that occupation occurred on top of a number of natural mounds. Three of the mounds have been excavated. Two sections have been sampled at Koldihwa, Z1 and Y1 (see figure 5.5 for table of the samples taken). Both of these were taken on the same mound located close to the riverbank. The total habitation deposit of both of these sections is 1.70m deep. Both sections have the same phases present. They are comprised of five layers from Neolithic to Iron Age deposits. Layer 5, at the bottom of the sequence, is a sterile layer that the Neolithic deposit sits on. The Neolithic phase is comprised of two layers, 4 and 3, and is identified through the pottery wares including cord-impressed, plain red, and crude black and red ware. Layer 2 sees the introduction of Chalcolithic pottery wares, which are wheel-made, and use well-levigated clay. Layer 1 demonstrates Iron-Age deposits. This layer has circular pits dug down in to other layers, which are thought to be for rubbish disposal. One of these pits was sampled for phytoliths in section Z1.

Direct AMS dating of the macro-remains recovered in this project has allowed new dating of this site. These can be seen in figure 5.6. From these dates, it is clear that as suggested in chapter 4, the early dates previously found are anomalous and the date of the 2nd millennium BC fits well with the dating conducted in this project. With the new dates it can be concluded that the Neolithic deposits begin about 1800 BC and last for about 1000 years. Chalcolithic deposits, which are defined using pottery, probably begin about 800 BC. The Chalcolithic and Iron Age deposits are very close together in date and do not seem to span as long as the Neolithic deposits.

Mahagara

Mahagara lies on the right bank of the river Belan, opposite the site of Koldihwa, and about 85km from Allahabad (Sharma et al. 1980a). The site itself is protected by a ridge along the river composed of Palaeolithic geological formations. There are 2.60m of habitational deposits and all of this is of one single cultural phase (Neolithic). There is no Chalcolithic material, like the artefacts found at Koldihwa, present at this site. The samples taken for this project come from the 'index square', which was excavated down to the natural soil in the southern part of the site (see table in figure 5.7 for the samples taken). This revealed 17 layers. These are divisible in to six structural phases. The early levels (layers 17 and 16) are found in limited areas over the site and do not have any structural evidence. From the middle of the section there is structural activity and the uppermost levels have the most structural evidence with house plans and floors. There is no detailed stratigraphic information given in the site report about the structural phases and how these relate to the layers.

The new dates conducted on the macro-remains recovered for this project demonstrate consistent dates with those previously taken at this site. The deposits are likely to begin about 1700 to 1600 BC and the middle phase of the site is probably about 1500 BC. The site was abandoned before the transition to the Chalcolithic phase ca. 1400/1300 BC, unlike most sites in the region that continue directly into this phase.

5.1.2 Site selection and sampling in Orissa

A field season in Orissa was conducted in September-October 2003 and this recovered samples from a number of sites with long temporal sequences and also from what appeared to be short lived semi-sedentary sites. Sites were selected that had been previously excavated or surveyed by the Indian collaborators (Dr R Mohanty – Deccan College, Pune, Dr K Basa, and Dr B Mohanta – Utkal University, Bhubaneshwar). These sites were thought to have the potential to recover archaeological plant remains. Two lowland sites in South Orissa (Puri District), Gopalpur (GPR), and Golbai Sasan (GBSN), have been previously explored and the later excavated but no archaeobotanical sampling had taken place (Sinha 1993, 2000, Mohanty 1994, Kar 1995-1996, 2000, Kar et al. 1998). These sites are both extensive mounds with cultural sequences spanning the Neolithic through to the Iron Age. Therefore, systematic sampling was conducted at both of these sites by exposing a clean section at the side of the mounds with direction from the excavators (see figures 5.8 and 5.9). Bulk samples (20 litres) and phytolith samples (approximately 100ml) were taken from all the stratigraphic layers. Sampling at Gopalpur was hindered by a high water table, which prevented some of the lower levels being sampled but Neolithic deposits may still have been sampled.

In the same field season, a number of sites were sampled in Central and Northern Orissa (in the districts of Dhenkanal and Mayurbhanj) but none of these had long sequences and probably represent more short lived sites or seasonal camps. The sites sampled were Bajpur, and Banabasa. Sampling at Bajpur and Banabasa was conducted by digging 1m by 1m trenches and taking samples (20 litre bulk and phytolith samples) every 10cm until sterile deposits were reached (see figures 5.10 and 5.11 for photos). Another site was sampled in this same area (Dhenkanal district), Malakhoja, which is located close to the site of Sankerjang. This site had more sunstantial deposits than the other sites in this area and was in fact a small mound. Therefore, Malakhoja was sampled from a freshly cut section as had been conducted at other such mounded sites in South Orissa and 20 litre bulk samples and phytolith samples were taken (see 5.12 for photo of section). The stratigraphy at this site was not as clear as the mounded sites in South Orissa and contained few visible artefacts.

Golbai Sasan

This site has already been described in chapter 4 but the stratigraphy will be explained again here in relation to the samples taken. Golbai Sasan is a large mounded site with habitational deposits of about 6 metres (Sinha 1993, 2000, Mohanty 1994). The Neolithic deposits have been reported by the excavators to only cover a very small area and therefore the section sampled in this project probably does not include this phase (Sinha 2000). The mound is divided in to two by a road that goes through the eastern side. The section was sampled on the east side of the western mound at the side of the road. The Chalcolithic deposit is the most substantial at the site and is likely to make up the majority of the sampled section. This phase consists of 10 layers and the lower levels have structural evidence. The sample numbers start from the top of the section and descriptions of the soil and levels can be seen in figure 5.13. No samples were taken from layers 2, 4, and 6 because these were hard laterite layers and also no sample was taken from layer 4A because it was too thin. The very upper layers of this section could be Iron Age deposits.

There are a number of dates that have been published from the original excavation, but they are rather contradictory. Neolithic levels have produced a date of 1200 BC and the Chalcolithic deposits have dates at the bottom of 2950 BC. There are also other Chalcolithic dates from higher up the site of 3350 BC and 950 BC. A new set of dates has been conducted on grains from the new samples taken in this project and these make more sense than the previously published dates (see figure 5.14). The bottom of the sampled section (13D) is dated to 1265 BC and 1215 BC. Sample 9 is about in the middle of the section and is dated to 1220 BC. Sample 3 is near to the top of the section and gives a date of 1215 BC. All of these dates are quite late and suggest a very short time span of the site even though this site has substantial deposits. All of the ceramics collected from the environmental samples also suggest Chalcolithic deposits. The new dates do suggest a rather short period for such a substantial site and this could result from how the samples have been taken. They may well come from eroded material that has washed successively from the top of the mound even though there appeared to be clear stratigraphy. Even if this is the case, the samples can still be used to examine the Chalcolithic phase of the site although interpretations of change through the section are proposed with caution.

Gopalpur

Gopalpur is another site with a substantial mound and the habitational deposits are about 4 to 5 metres in height (Kar 1995-1996, 2000, Kar et al. 1998). It is hard to tell the exact extent of the mound in antiquity because the area is being extensively cultivated today and therefore much of the site has been ploughed away. This site has not been excavated and consequently there is little stratigraphic information available. The sampled section was taken on the southeast facing section of the mound, which is also the side where the river cuts through the site. The sample numbers start from the bottom of the sequence, which was as far down as could be sampled because of the high water table level at the time of year the site was visited (see figure 5.15 for table of the samples taken). Even though there is Neolithic pottery at this site, there is no information as to the extent of Neolithic deposits or whether there are any at all because this type of pottery is also found in Chalcolithic deposits. From the flotation sample, black and red ware pottery was found in the lowest samples and throughout the section. This type of pottery is thought to be consistent with Chalcolithic cultures and therefore the lowest sample is probably of Chalcolithic age. This could mean that this site is exclusively Chalcolithic or that the Neolithic deposits are restricted as has been found at Golbai Sasan.

There are no previous dates for this site so the dates conducted in this project are the only dates available so far. The dates taken do make a good sequence of dates and make sense in terms of a chronological sequence by getting older down the section. Sample 2 at the bottom of the sequence gave a date of 1395 BC. Samples 6 and 8 gave dates of 1265 BC and 1320 BC respectively. At the top of the section, sample 13 gave a date of 1170 BC. These are all Chalcolithic in age, which was expected from the material remains.

Malakhoja

Malakhoja is another mounded site but not as substantial as Gopalpur and Golbai Sasan. It lies close to the site of Sankerjang, in Dhenkanal district. A section was sampled at the side of this site where 10 flotation samples were taken and four phytolith samples. The deposits were about 1.40 metres in depth and all consisted of a red sandy sediment. There did not appear to be much anthropogenic inclusions and particularly no organic material was obvious. This site is thought to be Iron Age in date but there is no previous dating. No dating was conducted for this site in this project because insufficient organic material was available (see figure 5.16 for table of the samples taken).

Bajpur and Banabasa

Both of these sites have been described in as much detail as is available in chapter 4. Neither of these sites presented any stratigraphy or artefacts in the trenches excavated for environmental sampling (see figures 5.17 and 5.18 for a table of the samples taken). At Bajpur, four flotation samples and five phytolith samples were taken. The topsoil was taken as a sample for phytoliths but not for flotation because it will probably reflect the local vegetation rather than the archaeological remains. At Banabasa, three samples were taken for flotation and four for phytolith analysis. There was no pottery present at this site and only finds of lithics were found on the surface. There is no dating for these sites although they have been suggested to be Neolithic from the lithic remains (ground stone axes) found on the surface of the sites. Unfortunately, there was not sufficient archaeobotanical material for dating in the new samples taken for this project from either of these sites.

5.1.3 Extractions methods in the field

Macroscopic remains

Flotation was carried out at all the sites mentioned above. This consisted of a bucket flotation method using 500 micron sieve bags for the flot and 2mm sieves for the heavy residue fraction. The nature of fieldwork in India means that flotation methods have to be portable and low-tech; therefore flotation machines are not practical. Efficient recovery of macro-remains is also necessary in India and bucket flotation offers the best method for this because it is easier to check that all the flot material has been collected. Once processed, the flots and residues are dried in the field and the residues are sorted for plant material so that it can be transported back to the UK with the flots.

5.2 Laboratory methods

5.2.1 Extraction in the laboratory

Macroscopic remains

Once back in the UK, the samples are sorted for all the botanical remains. The whole of the sample is sorted as the flots are usually not very large. Firstly, the flot is separated in to different sized fractions (2mm, 1mm, 500 microns, and less than 500 microns) to enable the extraction of plant material from the flots. All plant material is removed from all the fractions using a low powered binocular microscope. Charcoal is only removed from the 2mm fraction. Once all the botanical material is separated it is ready to be identified.

Microscopic remains

There is no standard extraction method for getting phytoliths from sediments. Each laboratory has a different way of processing sediments with advantages and disadvantages in using each method (Lentfer & Boyd 1998, 1999, Madella et al. 1998). All the procedures are based on the same principle of removing the soil particles to leave the phytoliths clear when mounted on the slide. This involves removing the clays, carbonates, organic matter, and oxides of iron or aluminium (Pearsall 2000, Piperno 2006). Heavy-liquid flotation methods are the most common procedures used. The heavy-liquid involved varies and includes bromoform and acetone (Oberholster 1968), bromoform and tetrachloromethane (Twiss et al. 1969), tetrabromethane and absolute ethyl alcohol (Rovner 1971), potassium iodide, and cadium iodide (Carbone 1977, Piperno 1988, Pearsall 2000), zinc bromide (Mulholland 1985), and sodium polytungstate (Hart 1988, Rosen 1995, 1999, Madella et al. 1998). All are adjusted to a density of around 2.3 for the phytoliths to float at the final stage of the processing. Sodium polytungstate is the only one of these chemicals that is non toxic and therefore not dangerous to use. Consequently, the development of a method using sodium polytungstate is much better than exposing researchers to toxic substances.

Rosen (1995) has developed a technique using sodium polytungstate that although being complex does produce excellent results. Madella et al. (1998) have produced a less complicated procedure using predominantly centrifugation to remove the soil particles. It does have the advantage of using only two containers and therefore is less likely to have accidental loss of phytoliths. However, the author has used both methods and the Madella et al. (1998) technique is not as efficient as the Rosen method for getting rid of the soil particles. The phytolith assemblages are much cleaner using the Rosen method because the organic matter is burnt off and the clays are settled using gravity. The cleaner end product of this method makes it easier to count and recognise the phytoliths. Using more containers in the Rosen method could be seen as a disadvantage but if the researcher is thorough when transferring between containers then there should be minimal loss of sample. If this same procedure is followed for all the samples then any loss should be equivalent throughout.

The Rosen method of extraction is therefore used in this project and this procedure also encompasses Albert & Weiner's (2001) quantitative approach. This allows densities of phytoliths in each sample to be calculated by measuring weights throughout the extraction process. With this method, there must be great attention paid when mounting the slides to get the material spread out evenly. Calculations must be adjusted if there are a lot of other remains present in the sample apart from phytoliths such as diatoms. Other methods can be used for quantitative evaluations, such as the use of Lycopodium spores, but there are also problems with these methods (Powers & Padmore 1993) and therefore the former method is thought to give the best quantitative data. Full details of the extraction method used in this project can be found in appendix 5.1.

5.2.2 Identification

Macroscopic remains

Identification proceeds by comparing the recovered plant remains to the modern comparative collections at the Institute of Archaeology, University College London, and relevant pictures of reference material (Noda et al. 1985, Vaughan 1994, Galinato et al. 1999, Nesbitt 2006). The identification of macroscopic plant material is not always straight forward. The nature of archaeobotanical remains means that the material is usually fragmentary and only certain parts of the plant survive. Indian material also has many taxa that are problematic to identify to species level (rice, native pulses, and small millets) and wild species for which reference material and illustrated guides are not available. These problems have been thoroughly investigated recently by Fuller (1999, 2002a) for the cultivated crops and therefore will not be reiterated here. The methods used by Fuller (1999, 2002a) will be used for identification in this project and are briefly discussed below.

Morphometrics and size ratio can be used to overcome some of these problems of identification. However, measurements need to be considered as part of a population and therefore individual measurements are meaningless (Hubbard 1992, Fuller 2002a). The effect of charring on size also needs to be considered as this may cause difficult differentiation of some species groups on the basis of length-breath ratios, such as Indian *Vigna* species. Experiments are currently taking place to reassess this issue and its implications on the identification of charred pulses (Jupe 2003, Jupe & Fuller in prep, Fuller & Harvey in press). Rice is another crop, which is commonly measured for identification (Vishnu-Mittre 1961, Constantini 1987, Oka 1988, Wenming 1991, Thompson 1996: 176, Chen & Jiang 1997) but this approach also needs to be re-examined especially in India. This will be conducted as part of this thesis and is reviewed in chapter six.

In addition to morphometrics, the examination of archaeobotanical specimens under a scanning electron microscope can be used to correctly identify some Indian plant species. The identification of specific millets, rice, and pulses benefit from this type of analysis because certain species have distinct surface patterns (Fuller 1999, Fuller et al. 2004, fig. 6). A key for the identification of small millets can be seen in figure 5.19.

Parenchyma is another important class of macroscopic plant material that is recovered during flotation. This material will be separated from the seeds and other macro-remains during sorting and identified separately. High level magnification is needed for the identification of parenchyma and usually SEM is required. However, few comparative collections are available and none specifically for India. Some work has been conducted in Southeast Asia (Hather & Kirch 1991, Hather 1994, 1996), which could be used as a starting point to attempt identification of any such material that was present in Indian samples.

Microscopic remains

Establishing a reference collection for Indian crop plants and associated weeds was an important part of this project. It is essential that this is conducted so that the archaeological phytolith assemblages can be identified in more detail and therefore a greater degree of data analysis can be applied to the samples. The focus of the reference collection is economic plants of India but also associated wild plants such as wild ancestors and weeds.

Plant material can be made into reference slides for phytolith analysis in a number of ways including dry ashing (Parr et al. 2001a), microwave digestion (Parr et al. 2001b), spodograms (Pearsall 2000), and chemical oxidation (Pearsall 2000). The type of plant material and whether measurements are going to be taken can determine which method is needed. If measurements need to be taken throughout the plant part then spodograms are a good option because they leave the cells undisturbed. This also helps to understand the morphology of the plant, where particular cells occur in the plant, and can be used to identify multi-celled phytoliths. Chemical oxidation, microwave digestion, and dry ashing require the plant material to be cut up prior to the processing therefore the phytoliths on the slides will be broken up to some extent.

Dry ashing and spodograms were used to establish the reference collection for Indian plants. Both these methods will be used to examine crop plants but spodograms are especially important because attention needs to be given to how to identify plant parts as well as being able to identify the plant genus or species. Details of these methods can be seen in appendix 5.2 and 5.3.

A review of phytolith systematics is not given here but for a good review of the European history of the discipline see Powers (1992). Most arable crops have been researched in terms of phytoliths; maize (Pearsall 1978, 1982, Piperno 1984, Piperno & Pearsall 1998, Piperno 2006), rice (Watanbe 1968, Pearsall et al. 1995, Zhao et al. 1998, Zheng et al. 2003a), common bean (Bozarth 1990), sugar cane (Madella 1995, 1997), New World curcurbits (Bozarth 1987, Piperno et al. 2000, Bryant 2003, Carter 2003), roots and tubers (Carter 2003), fruits and vegetables (Wilson 1985, Cumming 1992, Mindzie 2001) and wheat and barley (Rosen 1992, Ball et al. 1993, 1996). India presents somewhat of a challenge for phytolith analysts because many of the crops that are used have not been thoroughly examined and therefore established criteria for identification are not available for all crops. Native Indian millets and pulses are common components of archaeobotanical assemblages and phytoliths from these taxa need to be characterised. Fujiwara et al. (1992) have supposedly identified finger millet in Harappan samples but have given no details about how they were identified. Krishnan et al. (2000) have constructed a key of single cells from Indian grasses, which includes many types of millet. However, it is hard to believe that the identification of millets can be achieved just from measuring short cells because when looking at reference material the size varies considerably and there seems to be significant overlap.

The approach taken for identifying plant types in this project is to use descriptions of multi-cell panels following the example of work conducted on wheat and barley species by Rosen (1992). These rely on a number of characteristics unique to the plant and all of these distinguishing features must be seen before the identification can be made. Identification using this method has been started on millets during the authors M.Sc. thesis (Harvey 2002) and will be continued during this project as well as studies of other common economic plants such as Indian pulses, curcurbits, and palms.

Morphometrics are also used in phytolith analyses to distinguish between plants at genus and species level (Ball & Brotherson 1992, Ball et al. 1993, 1996). Single-cells can also be unique to certain plants and morphometrics has been used to distinguish these at a high level. Rice has many cells that can be recognised: bulliforms (Fujiwara 1993, Zheng et al. 2003), bilobes and double-peaked glume cells (Pearsall et al. 1995, Lu et al. 1997, Whang et al.1998, Zhao 1998) but it is not clear at present to what taxonomic level these morphotypes can be identified. An examination of the morphometric methods used to identify rice is part of this project and is discussed in the next chapter.

Plants that are common arable weeds can also be recognised. *Phragmites* sp. and *Arundo donax* are particularly distinctive (Greiss 1957, Ollendorf et al. 1988). Cyperaceae can also be identified easily to family by recognising the distinctive cones (Ollendorf 1992). Palms are another type of plant that can be recognised using phytoliths and this will be explored further in this thesis as usually only date palm is identified. India has many palm species that may have been utilised in antiquity and two particular species of economic value are coconut and palmyra palm. A brief discussion of the findings found during the examination of reference material is presented in chapter 7.

Short cell grass classification schemes are frequently used and this will be applied to the samples (Twiss et al. 1969, Brown 1984, Mulholland & Rapp 1992a, 1992b, Pearsall & Dinan 1992). This means that the quantity of phytoliths in each of the ecological groupings can be compared. The Twiss et al. (1969) classification scheme was based on Bowden's (1963) re-division of grass subfamilies using microscopic characteristics. Many floras have published percentage data for these subfamilies but this has caused a biased view of their occurrence in certain environments (Cross 1980). Cross (1980) has reassessed these data and concluded that there are three main areas that these subfamilies can be classified as occurring in; C_4 tropical group includes *Andropogoneae*, *Paniceae*, *Chloridoideae*, and *Aristideae*, C_3 sub-tropical contains *Arundinoideae*, and C_3 North temperate group is

Pooideae (Festucoids). This means that in South Asia the C_4 tropical group should dominate the phytolith assemblage with a few grasses from other subfamilies.

Descriptions of the phytolith categories identified in this project can be seen in appendix 5.4. This outlines the terms used to describe the phytolith morphotypes in the text and also a description of the morphotype using the International Code for Phytolith Nomenclature 1.0 (Madella et al. 2005). Multi-celled phytoliths are described in detail with appropriate diagrams.

5.3 Qualitative and quantitative analysis

Macroscopic remains

Archaeobotanists approach the numerical analysis of archaeobotanical remains in many different ways. It depends entirely on the amount of plant remains that are found and also the type of questions that are to be addressed. It is important to remember that archaeobotanical datasets are incomplete and therefore interpretation should progress with a certain degree of caution. The influences of taphonomy on the assemblages must be considered and this issue is discussed in depth below. Before beginning quantitative analysis of data the following points must be considered (Pearsall 2000): i) do not use statistics that you do not understand; ii) begin with simple tabulation and then work towards more complex techniques; iii) do not use approaches that require more rigor than the data is capable of.

The most basic form of analysis is qualitative presentation of data. This is presenting the presence/absence or scales of abundance of species that appear on the site. Detailed descriptions are usually given in such cases and this level of data presentation is only really appropriate for initial reports of archaeological material.

To address any archaeological questions, quantitative analysis must be attempted on the archaeobotanical dataset. Quantitative analysis can be split in to two types: i) non-multivariate and ii) multivariate. Non-multivariate analysis includes counts or weights of items, tables, ratios, densities, ranking, species diversity, and ubiquity. These methods are used predominantly in archaeobotanical analysis. They suit smaller data sets with a manageable amount of taxa but can also be used on large data sets. All archaeobotanical reports start with a table of either counts or weights of items recovered. These are the absolute counts. The data can be assessed in its raw form or can be reduced, standardised, and transformed to reduce skewness in the dataset (Jones 1991). After this simple presentation of the data, the direction that data analysis progresses, depends on what questions are being addressed.

In this project, it must be considered how to record items in the samples. The fragmentary nature of the material means that counting is an issue, which has to be considered carefully. Therefore, complete seeds, chaff, and other plant parts are recorded as one item in the tables. The majority of cereals and pulses are not whole and therefore the number of halves and quarters are also recorded. Calculations will be made to estimate the number of complete grains in each sample where halves are counted as 0.5 and quarters as 0.25. A total number of items will also be calculated as well as the number of items per litre of sediment to give an idea of the density of archaeobotanical remains per sample.

Simple quantitative methods can be used to investigate many archaeological questions. Ratios are a direct way of analysing data and help to standardise it. It is a good way of comparing samples of unequal size, samples differing in circumstances of deposition or preservation, and comparing quantities of different categories of material that are equivalent in some respect (Miller 1988). Ubiquity values, which are the percentage of a taxon in the site or phase, are a very useful but simple method of analysis. This is a form of denominator ratio. Ubiquity analysis can reinforce presence/absence information and its strength is that the score of 1 taxon does not affect the score of another (Popper 1988). Therefore different taxa can be evaluated independently. This method provides the relative importance of taxa and can be used to focus on changes in importance of specific plant species within and between sites. Along with a relative method of analysis such as ubiquity, it is essential to compare the outcome with an absolute method, such as assessing raw data, to give an overall assessment of the data.

Comparative ratios can be used to compare two items and are helpful for answering specific questions. Comparing different plant parts either macro-remains or phytolith morphotypes can be used to address issues of crop processing as discussed in the section below. This can demonstrate whether these plant parts have the same pathway in to the site (Harvey & Fuller 2005). Ratios can also be used to demonstrate one taxon replaces another over time, or that one food plant increases in use over another (Pearsall 2000). Therefore, using simple methods of data analysis can produce a high degree of interpretation. It is important to present data simply showing a clear route to the interpretations and therefore the results can be understood by any audience.

Multivariate analysis is still not commonly used by archaeobotanists. As mentioned above, most archaeobotanical assemblages can be interpreted using simple qualitative and quantitative methods. Multivariate methods tend to be directed at specific questions such as the study of weed ecology and the interpretation of crop processing stages. Phytosociology, autecology, and "FIBS" are applied by archaeobotanists to the study the weed ecology of species present in the archaeobotanical assemblage (Jones 1987, van der Veen 1992, Charles et al. 1997, Bogaard et al. 1999, 2001, 2005, Jones et al. 2000, 2005, Bogaard 2004). Using these methods on Indian assemblages is challenging because data on Indian weed ecology is not readily available. There is also the problem that archaeobotanical criteria for weed identifications is still poorly developed. However, some general aspects of weed ecology may be informative for prehistoric India by suggesting aspects of growing conditions such as wetland weeds indicative of wet-paddy rice systems. This can be applied to the phytolith assemblage as well as the macro-remains as long as good enough identifications can be made.

As the macro-botanical dataset is not particularly large in this project, multivariate methods will be restricted to the methodological investigation of rice identification. Simple methods of analysis will be used on the macro-remains data such as ubiquity and ratios to compare within and between the sites. This analysis, in combination with the phytolith assemblage data, will hopefully give a detailed interpretation of the economies of the sites under investigation.

Microscopic remains

Many of the same issues of quantification, as have been stated above for macro-remains, also apply to phytolith analysis such as the importance of considering taphonomy and the limitations of the dataset. Counting methods for phytoliths vary according to the researcher. Qualitative analysis such as quick scans giving an abundance scale for morphotypes is the simplistic way of summarising samples. However, quantitative analysis allows a greater degree of data analysis that can be combined with the macro-botanical data set. Therefore in this project, the phytoliths are examined under a transmitted light microscope at 400 x magnification. The slides are scanned in rows using a standard single-cell and multi-cell scan procedure (Piperno & Pearsall 1993, Pearsall 2000). It was aimed to count between 300-400 single-cells and 100-200 multi-celled phytoliths in each sample but this may not be possible on all slides. In those cases, the entire slide is scanned. The number of microscope fields counted per slide will also be recorded to allow the calculation of the density of phytoliths in each sample (Albert & Weiner 2001). This allows the phytolith types in each slide to be compared as well as the densities between the samples. The densities are calculated per gram of sediment and this means that the phytolith counts are standardised. The raw counts are not used for data analysis because they are not quantitative in terms of relating directly to the amount of the phytoliths in the particular sample but are just counts of what has been encountered on the slide. Adjusting these raw counts to densities aids comparisons of phytolith morphotypes within and between samples. Relative frequencies of the raw counts will be calculated and compared to the absolute counts because the former method is the usual form of analysis used by phytolith analysts. There are draw backs with using relative frequencies because it emphasises morphotypes with the highest values and therefore may not draw out patterns as well as absolute counts.

As with macro-remains, it is important to start data analysis of the phytolith assemblage in the simplest way. This usually means to look at the density of phytoliths overall in samples and compare this over time and between sites. This can begin to suggest whether the sites have had substantial input of plant remains or not. Examining also which phytolith morphotypes are present in high or low values will move towards more firm interpretations such as looking at the level of grass phytoliths compared to dicotyledon phytoliths. Specific morphotypes that relate to crop plants are obviously important to concentrate on during the analysis phase and the densities of these in the assemblage can be related to the use of these crops in different phases of the site.

Some researchers utilise methods from palynology such as stratigraphic bar charts showing changes in phytolith morphotypes or groups over time (Pearsall 2000, Piperno 2006). These are useful for looking at changes over time in general groups. Palynological methods of data analysis are good for answering certain questions about general changes and these methods are used when pollen analysis is being combined with phytolith data. This could be used in this thesis to combine the macro-remain data with the phytolith analysis. However, as there is a combination of macroscopic and microscopic analysis in this thesis, the phytolith data can also be treated like the macro-botanical data set as it has been sampled from the same locations. The strength of phytoliths is that plant parts can be identified as well as specific plant families, genera or even species just as in macro-botanical identifications. This means that the data set can be approached in much the same way as analysing macro-remains of seeds and chaffs.

At a basic level, quantitative methods such as ubiquity could be used to assess the data and the relative importance of different plants and plant parts. This will also allow the comparison of the phytolith data with ubiquity values from the macro-botanical assemblage, which can add more weight to arguments about the importance of certain crops at certain times and in certain areas.

Ratios can also be used to compare phytolith morphotypes. Comparisons can be made between different plant parts to investigate the input of these parts in to the deposits. This method can be used to assess the origin of the sample and this will be discussed in more detail in the taphonomy section below. Such methods have been used to determine environmental conditions around sites by showing a dominance of certain floras such as grassland or wetland habitats. Samples from archaeological sites should be considered as selected by humans and therefore the remains will relate to human activities rather than a complete picture of the local environment.

5.4 Taphonomy and approaches to the analysis of crop processing activities

Interpretations of the archaeobotanical data must always be considered in terms of the taphonomy of the samples. Firstly, there is a depositional bias, which is what plant material gets in to the site. This will be affected by the general environment and climate of the area as to what plants can be exploited and grown at the site. There is also the filter of human choice which directly affects what plant material ends up at the site (Dennell 1972). Plant material can also be brought on to the site accidentally such as seeds of weed plants transported on animals or naturally transported such as wind blown seeds but this will account for a very small proportion of the plant remains and is also unlikely to be preserved unless, for example, animal dung was being used as a fuel (Helbaek 1969, Miller 1984, 1993, 1997, Miller & Smart 1984, Neff 1989, Hillman et al. 1997, Charles 1998, Samuel 2001, Madella 2003).

Secondly, preservation determines what plant material will survive in the sediment. Macro-botanical remains are commonly preserved as charred material but could also survive through waterlogging, desiccation, or mineralization. Plant material coming in to contact with fire on the site is very selective in terms of what plant material will become charred. It is important that the plant material is only exposed to low temperatures otherwise it will be incinerated. This can occur in a number of ways (Hillman 1981): i) during the drying or parching of the crop product; ii) burning a diseased crop; iii) use of crop waste as fuel and incorporation of waste into dung as fuel; iv) accidental burning during cooking or destruction of a house by fire. This may suggest that macro-botanical material is most likely to come from daily processing waste (Fuller 2002a, Stevens 2003). Differential preservation also has to be considered because many plant parts are fragile and will be burnt away in fires therefore not surviving archaeologically (Boardman & Jones 1990).

Lastly, there is a bias in the recovery of the samples. Where and how a sample is taken will affect the outcome of the archaeobotanical assemblage of a site. Different sampling strategies mean that there is more or less chance of recovering all the information possible from a site. Flotation methods also affect the recovery of plant material such as sieve sizes and the quantity of bulk sample taken. All of these factors must be considered while interpreting archaeobotanical samples.

It has already been discussed in chapter two, how the content of a sample can be an indicator of crop processing activities even though they come from secondary or tertiary deposits (Fuller et al. in press, Harvey & Fuller 2005). This is very different to most other archaeological work that relies on the context to help with interpretations. This new approach, however, has grown out of the earlier founding work of Hillman (1973, 1981, 1984) who created models of crop processing activities using ethnographic studies from Turkey. This work has been developed by Jones (1984a, 1984b, 1987) particularly for wheats, barley, and some pulses from the western Mediterranean. These crop-processing models for application in archaeobotany were developed from observations of present day traditional, non-mechanized agricultural communities. It is important to consider how different methods of processing the crop will affect the composition of grains, chaff, straw, and weeds in an archaeological assemblage. The application of crop processing models to archaeobotanical assemblages is now fairly routine and models have been developed for many other crops and regions: barley and rye in Fennoscandia (Englemark 1989, Viklund 1998) and western Mediterranean (Peña-Chocarro 1999); quinoa and other crops in Peru (Bruno & Whitehead 2003); millets in India (Reddy 1991, 1994, 1997, 2003), in China (Lu 2002), in Nepal (Lundstrom-Bandais et al. 2002), in Africa (D'Andrea et al. 1999, Young 1999, Young & Thompson 1999); and rice in Thailand (Thompson 1996). All of these models focus on the use of macroscopic remains to interpret crop processing stages. These remains have certain issues associated with them such as their reliance on charring for preservation and the differential preservation of plant parts (Harvey & Fuller 2005). These problems can affect the proportions of plant parts in archaeological assemblages on top of the filters of crop processing. In particular, this will affect light plant parts and fragile weed seed, which are more likely to be incinerated (Boardman & Jones 1990) and also early processing stages are less likely to be represented as they are unlikely to come in to contact with fire (Jones 1987, van der Veen 1992, Stevens 2003). There is also more chance of the early processing waste being seasonally produced and remaining off-site. This will therefore effect interpretations especially when trying to distinguish between crop consumer and crop producer sites (Fuller & Madella 2001, Smith 2001, Fuller 2002a, Stevens 2003, Harvey & Fuller 2005). Routine daily processing is therefore more likely to be represented and allows inferences to be made about the scale of labour organisation.

Another aspect of preservation to consider, especially for this thesis, is the amount of organic remains that are preserved at tropical sites. As mentioned previously, the quicker turn over of carbon in tropical regions leads to much poorer preservation conditions on most sites (Hather 1992, Piperno & Pearsall 1998). This is the reason why, in this thesis, there is a combination of macro-remains and phytolith analysis. A new approach to interpreting crop processing stages has been developed, which uses phytoliths (Harvey & Fuller 2005). Phytoliths have the advantage that they are inorganic and therefore particularly durable over long periods of time. They do not rely on special preservation conditions such as carbonisation, to be preserved archaeologically. Therefore, they allow another insight in to the ancient plant remains, which can be used in combination with macro-remains. Phytoliths may therefore be able to detect the earlier stages of crop processing that are unlikely to preserve macro-remains through carbonisation. There are a number of problems with using phytoliths, which are discussed in Harvey & Fuller (2005) but the main issue that has to be overcome is the level of identification. Plant parts as well as the type of plant can be identified using phytoliths much like the identification of macroscopic remains. However, the identification of phytoliths to species level is limited. In this thesis, the methods used to identify rice phytoliths to species are investigated and this may aid this method of interpretation. Other plants such as millets and pulses can not as yet be identified to species accurately or in the case of pulses do not produce a great deal of phytoliths but this will hopefully be investigated further during this thesis.

The other factors that will effect what remains are found in the archaeological samples are the type of crops used and cultural influences on processing techniques. The type of crop has a primary role on the type of processing that occurs (Reddy 1997, Viklund 1998). Wheat and barley are found on prehistoric sites in India but these crops have been considered in some depth elsewhere so will not be discussed in great detail here. Rice, millets, and pulses are all important crops in India and have not been investigated thoroughly. How these different crops are likely to be processed and what parts are likely to end up in archaeological samples in an Asian and particularly Indian context will be discussed below.

A number of modern day studies have relevance to this thesis including the study of rice crop processing in Thailand by Thompson (1996) and Reddy's (1991, 1994, 1997, 2003) study of millets in Northwest India. There have been few studies of pulses and most of them examine Southwest Asian species (Jones 1984a, 1987, Butler 1992, Butler et al. 1999). A summary of current evidence for Indian pulses has been conducted by Fuller & Harvey (in press) but more dedicated studies are needed to observe the traditional processing of pulses. What all of these ethnographic studies demonstrate is that there are two major types of crops and these two groups have implications on the processing methods that are used on them and how many processing stages are necessary. These two groups are hulled crops and free-threshing crops. Hulled crops include glume wheats, rice, hulled millets, which tend to be the small millets native to India, and also 'pod-threshing' pulses such as horsegram (a native Indian pulse). Free-threshing species include barley, free-threshing wheats such as bread wheat, African millets including *Eleusine coracana*, *Pennisetum glaucum*, and some races of *Sorghum bicolor*, as well as most pulses such as *Lathyrus sativus* and the other Southwest Asian pulses, and also some Indian pulses including *Vigna* spp. The main difference in processing for these two groups is that the hulled species require a further stage of pounding to break the husk from the grain. This can sometimes include parching to help to release of the grain, which is common for glume wheats. There are further differences between these two groups that can be seen in the processing methods, which will be discussed along with regional traditions for the relevant area.

Harvesting has potentially the greatest impact on what is later included in the archaeological assemblages (Harvey & Fuller 2005). There are a number of options open to harvesters of rice, millets, and pulse crops (see figures 5.20 and 5.21 for rice and millet processing diagrams). Reddy (1994, 1997) suggests that it depends on the size of the panicle for millets. Large panicles found on millets such as sorghums and *Pennisetum* spp. are more likely to be harvested by cutting the top of the stalk and therefore just removing the panicle. This means that the stalk is not harvested and this will also reduce the collection of weeds. Smaller species of millet are gathered together in handfuls and cut at the base of the plant therefore harvesting some of the stalk and potentially more weeds. Pulses are either uprooted or hand picked. It has been suggested that early cultivators would have used hand picking because of the uneven ripening of primitive cultivars (Fuller & Harvey in press). This method would not select for weeds where as uprooting could potentially incorporate a substantial amount of weeds because of some pulses twining growing habit. However, the harvesting technique is probably also a cultural choice as well as being related to the particular crop involved.

Rice may also be harvested by just taking the panicle and therefore incorporates few weeds. Thompson (1996) suggests that rice crops do not generally contain a lot of weeds unlike wheat and barley. This can be the result of thorough plot clearance, the drowning out of weeds by wet rice practises, and also reaping using finger knives. The use of finger knives is restricted to certain regions mainly in China and Southeast Asia and these tools are not usually used in India. Weeds are an important indicator of crop processing stages for wheats and barley especially for harvesting methods (Hillman 1981, Jones 1984a, 1987) and therefore the study of rice cultivation may be hindered because of the lack of weeds. However, dry field systems of cultivation do have more weeds present and rice may not always be harvested by taking just the panicle because the straw is in fact a highly valued commodity (King 1949, Srinivas 1976, Sherman 1990). It is as useful as the grain and can be used as food and bedding for animals, thatching for houses, fuel, mulch, and fertilizer. This means that the straw could be cut with the panicle or be taken during a secondary harvest. Both of these methods have been observed by the author in India. This does give more chance of weeds being incorporated with the harvest and the presence of wild taxa in archaeobotanical samples known to be rice weeds such as sedges and other grasses should be seen as potential sources of information about husbandry practises and crop-processing stages.

Threshing and winnowing may occur in the field or on specially constructed threshing floors on the edge of the village rather than directly next to the domestic environment. Threshing and winnowing separates straw, leaves, and light weed seeds. Free-threshing crops may be stored prior to threshing and winnowing but hulled crops are more likely to be processed further before they are stored. There are ethnographic accounts of threshing on a temporary surface of woven mating in the field (Srinivas 1976, Sherman 1990) and the author has seen the threshing of rice plants on a permanent mud floor on the edge of a village in Northern Orissa. This means that there is much less chance of these early by-products coming in to contact with fire during this process although they may be used later for some reason such as fuel or fodder (Watt 1892) causing more chance of carbonisation. Sieving tends to be used with wheats and barley separating the grain from the chaff and weeds by size. Rice and millets tend to be separated from chaff parts through winnowing using baskets and rakes rather than sieves, which are used on other crops (Thompson 1996, Reddy 1997, Lundstrom-Baudais et al. 2002). It has been suggested that pulses would also follow this pattern in the same region because of cultural preferences in husbandry practises although more ethnographic work is needed to fully understand why certain choices are made for processing pulses (Fuller & Harvey in press).

For storage or for further processing the crop would now be brought in to the domestic environment if it had not been already. The crop processing from this stage onwards is likely to be carried out on a daily basis. The earlier stages of processing generally happen on more of a communal basis or individual families may hire extra labour at this time of year because of the need to harvest in a certain time limit and then process to store the products while there is a lot of labour still around. The daily processing in the domestic setting makes it much more likely that the plant material will end up being carbonised in the domestic fire than the waste of previous stages. Waste of this stage has been suggested to make up the majority of preserved waste archaeologically therefore variation relates to how bulk initial processing is organised (Harvey & Fuller 2005, Fuller et al. in press). With glume wheats, parching can be used prior to pounding but is not essential. Pulses are also routinely parched for consumption or to dry them for storage (Fuller & Harvey 2005). This will increase their chance of ending up in the archaeological record. It has been pointed out that pigeonpea, which is rare in archaeological assemblages is not commonly parched therefore less likely to be preserved. Therefore, parching can happen as the result of a certain crop being used such as a hulled crop or can be a cultural/environmental choice. Glume wheats may be more likely to be parched when they are grown in cold climates and parching helps to dry them to prevent rotting.

Parching is not necessary for rice and millets but may still be used. Rice is generally dried in the sun prior to pounding and can be seen laid in front of houses throughout villages in India. The climate therefore influences the choice not to parch because the crop can be dried naturally. Thompson (1996) has suggested that rice may be underrepresented in the archaeological record because of the lack of parching and therefore is less likely to come in to contact with fire. Rice can alternatively be par-boiled before pounding to help release the grain (Watts 1892). Reddy (1994, 1997) suggests parching is more frequently used for processing hulled millets and parboiling is also used (Kimata 1989). However, whatever the process, waste products will be produced and the new application of phytoliths to investigating crop processing stages can help to understand why certain macro-remains are absent or rare (Harvey & Fuller 2005).

The discussion above has shown that interpreting early agricultural sites is not straightforward and applying both macro-remains and phytolith analysis will help to overcome some of the problems. Phytolith analysis can aid the understanding of preservation issues and macro-remains can hopefully help to confirm identifications of phytoliths, which consequently will give a more accurate interpretation. In the next chapter, the issues surrounding the identification of rice are addressed. This will hopefully aid the application of the analytical methods presented above and lead to a greater insight in to the social aspects of the early agricultural communities in Northern and Eastern India.

Chapter 6

Rice identification methodologies: problems and prospects

This chapter will focus on the identification of rice in an archaeological context. It will firstly set out some general characteristics of the rice plant both macroscopic and microscopic and then discuss the development of taxonomy in the genus *Oryza.* Possible wild progenitors and routes towards the domestication of the rice plant are examined briefly. A number of identification methods will be reviewed and these are specific techniques that can be used in Indian archaeological assemblages. The chosen methods are used on a new set of modern reference material to assess their successfulness at determining the species of rice or whether they can identify the wild from the domestic species.

6.1 Terminology for the rice plant including rice phytoliths

Before discussing in detail the issues of rice identification, it is best to set out the general terminology that is going to be used in this chapter to describe the rice plant and rice phytolith morphotypes. A diagram of the parts of the rice spikelet can be found in figure 6.1 and figure 6.2 shows photographs of the different rice phytoliths.

6.1.1 Rice plant anatomy

The inflorescence of rice is a terminal panicle attached to a long peduncle (Ahn 1993: 53-54). The panicle consists of numerous spikelets attached by stalk-like pedicels to the branching panicle. At the apex of each pedicel are two rounded rudimentary glumes and a raised abscission surface which fits the rachilla of the spikelet (Thompson 1996: 164-

166). The spikelets are laterally compressed and comprise of two sterile lemmas, a rachilla, and a fertile floret, which consists of the fertile lemma and palea, and the flower that develops in to the caryopsis. The caryopsis is also called a 'grain' or 'seed' but is morphologically a fruit.

The fertile lemma is large, boat-shaped, and has five nerves (Chang & Bardenas 1965). It partly encloses the palea. The lemma is almost V-shaped in cross section and coriaceous in texture. It has a terminal tuft of trichomes (hairs) and may have an awn on the distal end, which normally occurs in the wild species (Thompson 1996: 164-166). The awn is also covered with many trichomes. Both the lemma and palea are highly silicified at maturity. The fertile palea has a similar structure and epidermal features to the lemma but is smaller with just 3 nerves. It has no awn.

As well as the fertile bracts, there are two diminutive sterile glumes at the base of the fertile lemma and palea (Chandraratna 1964). They are rarely more than one-third the length of the latter. The sterile lemmas are almost equal in size, the upper lemma being slightly larger than the lower lemma.

The caryopsis is tightly enclosed by the fertile lemma and palea. The pericarp, testa, and aleurone layer cover the starch endosperm and embryo of the caryopsis. The embryo is at the basal part of the ventral side. This is also the side of the lemma and can be called the abdomen (Matsuo & Hoshikawa 1993). The opposite side, which has the palea is called the back of the grain (dorsal side). The rest of the grain consists of endosperm. The grain has two vertical ridgelines protruding on both of its sides (Matsuo & Hoshikawa 1993).

6.1.2 Rice phytolith descriptions

The genus *Oryza* has a number of phytolith morphotypes, which are distinctive from other genera in the tribe Oryzeae. The leaves of the rice plant produce distinctive fan-shaped or keystone bulliforms. Similar phytoliths may also be found in other grasses including Oryzoideae, Bambusoideae, Panicoideae, Arundinoideae, and Eragrostidoideae (Lu et al. 1997). However, those found in rice are very widely flared cells and come in a number of forms, which vary according to the extent of flaring and width of the top (Pearsall et al. 1995). The base is symmetrical. There are also varying numbers of chipped facets on the fan edge of the cell, which may allow identification to species and this is discussed in more detail below (Lu et al. 2002).

The fertile glumes (palea and lemma) of the rice plant have unique epidermal cells. Glume cells with single- and double-peaked hairs are common. The double-peaked hairs are produced abundantly and do not occur in other genera of the tribe. The single-peaked hair has been observed in a number of millets including *Setaria italica* and therefore is not a unique morphotype (Pearsall et al. 1995, Lu et al. 1997). Although, it has been noted by the author that rice has very deeply serrated epidermis, which is attached to the double- and single-peaked hairs while the millets tend to have clear dendritic cells and the peaks are more hook shaped. The term single- or double-peaked glume or husk phytoliths is used to refer to these rice phytolith morphotypes. These peaked phytoliths can occur as single cells or as multi-celled panels. The author has observed through modern and ancient material that multi-celled panels appear more commonly than single cells. This may be due to the high degree of silicification in these particular cells that seems to prevent breakage.

There are also a number of short cells that may be characteristic of the genus, if measured and compared to other grasses, but are probably more distinctive of the tribe. There are three short cell types that are produced in the leaf tissues: a dumbbell with scooped ends; a cross with raised corners; and a short cell with a dumbbell base and a thin plate extending perpendicular to it (Pearsall et al 1995). The 'scooped' bilobes are arranged horizontally and this seems to be a distinctive trait of the tribe because these dumbbells can be found in *Leersia hexandra* and *Zizania caduciflora*.

6.2 Rice taxonomy, domestication issues, and why identification is problematic

6.2.1 Rice taxonomy

Oryza belongs to the subfamily Oryzoideae, in the family Poaceae (Gramineae). This subfamily has tropical and temperate species (Vaughan 1989). South Asia has a number of genera other than *Oryza*; *Leersia*, *Hygroryza*, *Porteresia*, and *Zizania*. The genus *Oryza* is small, containing about 23 species, but its species are ecologically diverse. The genus *Oryza* was named in 1753 by Linnaeus (Vaughan et al. 2003). In 1886, DeCandolle (1886) was the first to suggest identifying wild progenitors to address the issue of agricultural origins. He identified rice as being from Southern Asia, from China to Bengal, although he attributed the domestication of rice to China. In 1910, Kuwada determined the somatic chromosome number of rice to be 24. Morinaga and colleagues (Morinaga & Fukushima 1934) did genomic studies of rice and assigned the genomic identities AA, BBCC, CC, CCDD to different species. This determined that the cultivars (*Oryza sativa and Oryza glaberrina*) were put in to the AA group and therefore their ancestors also had to be within this genomic group. However, it was not until the 1960s that Tateoka's work (Tateoka 1963, 1964) clarified the basic groups of species within the genus and he called these groups species complexes. A table of the current species complexes can be seen in Figure 6.3. Little has changed in the nomenclature for the genus since the 1960's. However, one notable addition to Tateoka's original work, which is important for this particular study, is the description of the new species *Oryza nivara* and therefore the revised circumscription of *Oryza rufipogon* in 1965 by Sharma and Shastry (1965). *Oryza nivara* and *Oryza rufipogon* are the likely wild progenitors of Asian domestic rice.

Oryza sativa, the Asian domestic species of rice, is an annual grass that is extremely diverse but the species can be divided into three major groupings of traditional varieties. The *indica* variety is usually slender with awnless grains, light green leaves, and many tillers (Vaughan 1994). By contrast, *japonica* generally has roundish, pubescent grains, dark leaves, and few tillers. The third variety is known as *javanica* or tropical *japonica* but it is not always separated from *japonica*. It typically has large, rounded, awned, pubescent spikelets, low shattering, and few tillers. Further sub divisions have been suggested by some scholars but are not generally used (Wang et al. 1998). Vaughan (1994: 66) suggests that morphological features alone are insufficient to identify these varietal groups, however some scholars do use certain morphometric criteria to distinguish them and the pros and cons of some of these methods will be discussed later in this chapter.

Intense selection outside of the more conventional shallow water paddy fields has created the great diversity found today in the domestic species, *Oryza sativa*, and consequently it can be grown worldwide in tropical, subtropical, and also in temperate regions. *Oryza sativa* can be cultivated in dryland or wetland fields. Some extreme ecotypes have been created such as deep water rice, which can be grown in water up to 4m deep and floating rice can be grown at even greater depths. Domestic rice varieties can be cultivated in altitudes from sea level to 3,000m. In the Indian state of West Bengal, and also in Bangladesh, four seasonal ecotypes are cultivated producing four rice crops a year (Chang 1995) and in many countries double-cropping is common having a wet and dry season rice crop. This enormous diversity in forms and consequently cultivation methods is a key factor in the debate about identification issues. *Oryza sativa* has so many different varieties that are grown today that its morphological features are very diverse within populations and also between different populations. This makes it extremely hard to distinguish the domestic species from the wild species especially when using the few morphological criteria available in archaeological studies.

6.2.2 Pathways to domestication

There is still much debate as to where, when, and how rice became domesticated. The wild progenitor of Asian rice is still under discussion although more recent genetic studies give the strongest evidence for this issue. Initially, African (*Oryza glaberrima*) and Asian rice (*Oryza sativa*) were thought to have a common origin (Chatterjee 1948, Chandraratna 1964: 3) and it has also been suggested that African rice had developed from Asian rice (Nayar 1973: 185-193). However, it is now accepted that these two domestic species have separate origins with different wild progenitors on different continents (Chang 1989, Ahn 1993).

The pathway towards domestication for the Asian species was initially thought to be polyphyletic. Watts (1891: 498-506) suggested that each different form of domestic rice had different wild progenitors. However, the development of the current nomenclature, which is based on genomic groupings, has meant that the potential wild progenitors have narrowed to just two candidates (*Oryza rufipogon* Griff and *Oryza nivara* Sharma et Shastry).

Oryza rufipogon is the perennial wild species. It can be found in open swampy habitats such as swamps, marshes, open ditches, swampy grasslands, and rice fields especially deepwater rice fields (Vaughan 1989, 1994). It grows in water 0.2 - 4m deep and prefers clay/loam soil and black soil. It is found at low altitudes from sea level to 1,400m. It is distributed widely throughout the world including monsoonal parts of India, Sri Lanka, the Southeast Asian mainland and islands, as well as Australia and parts of South America.

In India, it has many local names such as *balunga* (Oriya) and *pasaha* (Hindi) and it is sometimes used as a human food.

Oryza nivara is the annual wild rice species. It differs in its ecological preferences to the perennial wild species because it needs a seasonally dry habitat (Vaughan 1989, 1994). Therefore, it can also be found in swampy areas with *Oryza rufipogon* but prefers the edges of ponds and tanks, banks of streams, shallow ditches, and can be found in or around rice fields. It grows in shallow water up to 0.3m. It also grows at lower altitudes than *Oryza rufipogon*, from sea level to 700m. *Oryza nivara* has a much more restricted distribution including India, Bangladesh, Myanmar, Nepal, Sri Lanka, Cambodia, Laos, and Thailand. However, it may also occur in South China but is just not identified because Chinese taxonomists tend not to recognise this species. Its local Oriya name is *jharaha* and it is regularly eaten by tribal people, Bhramins on days of fasting, and by the poor (Raju 1999).

There are a number of theories as to which of these wild rice developed in to the domestic form. Three main views seem to be recurring in the literature. An evolutionary process from wild perennials to wild annuals to domestic rice is a common theory and can be seen in the domestication of other crop plants. This theory has been suggested for both African and Asian domestic rice by Chang (1995). It was made to fit in to the then available evidence for rice domestication in China (Chang 1989, 1995). Wild perennial rice has also been suggested to have given rise to wild annual and domestic species separately. Oka (1988) suggests there may be an intermediate type which evolves in to the wild annual in response to the natural habitat and evolves in to the domestic species as a response to human intervention. Wild perennial and wild annual rice could also have given rise to separate domestic varieties (Second 1984, Ahn 1993, Crawford & Shen 1998).

With all these theories it must be remembered that the domestication of rice is a process and not an event, especially not a single event and therefore could have happened more than once and in a number of different places. Ahn (1993: 28) is quite right when he suggests that all the controversy may be meaningless because domestication would not occur without human intervention (whether conscious or unconscious) and therefore perennial and annual rice species both have the potential to be domesticated. He also points out that there is no reason to believe the same evolutionary process occurred throughout Asia. The wild progenitors of rice are distributed throughout South Asia, Southeast Asia, and China, and consequently this means domestication could have occurred potentially anywhere and any number of times in these areas following different pathways.

Genetic evidence is our best clue to the question of how many times and from which wild types of rice the domesticated form evolved. Current genetic studies have suggested a polyphyletic origin for domestic rice (Cheng et al. 2003). It has been suggested previously that there are a number of substantial genetic distinctions between *indica* and *japonica* varieties and this suggests separate origins (Sato et al. 1990, Sano & Morishma 1992, Chen et al. 1993, 1994, Wan & Ikehashi 1997, Crawford & Shen 1998). Recent studies have gone further by linking the annual wild rice to *indica* and the perennial wild rice to *japonica* (Chen et al. 1993, 1994, Cheng et al. 2003). This is contrary to most archaeological evidence that is put forward, which proposes one origin in China (Glover & Higham 1996, Bellwood 2005). Therefore, current genetic evidence could be seen to suggest one origin for *japonica* in China and another origin for *indica*, one of which may be in India. The work by Cheng et al. (2003) indicates multiple *indica* origins. Both of these wild progenitors are lowland species and therefore domestication is likely to have occurred in these areas rather than in upland areas as suggested by some scholars (Hayden 2003).

This means that it is important to assess the identification methods used to distinguish wild species of rice from the cultivar. Some of the methods have been developed using Chinese material and therefore do these same methods work on Indian assemblages? Especially, if we assume separate origins, won't the initial domesticates be different in India and China?

There is also an inherent problem when studying the domestication of rice and that is the problem of obtaining true archaic specimens of wild rice because of continuous hybridization between wild, weedy, and domestic species of rice (Ahn 1993). This means that it is hard to assess whether the comparisons we are making today are correct. Therefore we must always be critical of our modern studies, especially when using them to identify ancient rice specimens.

6.3 Review of current rice identification methods

As mentioned above, the identification of rice is still a problem, especially distinguishing some of the wild species from the domestic ones. It is easy to identify rice from other cereals through the grains' distinctive gross morphology but differentiating between species within the genus *Oryza* is usually conducted using the morphology of the grains as well as the accessory parts. Taxonomists use various criteria to determine the species of rice including shape, size, articulation, rachilla of the spikelet, texture, tuberculation, existence of pubescence in fertile lemma, and the presence, length, and robustness of awn, and the sterile lemma. Therefore in modern populations of rice, the difference between wild and domestic species can be easily determined using multiple characteristics. A problem arises when trying to identify the species using one method as is the case in most archaeobotanical investigations.

Many methods have been put forward for use on archaeobotanical samples but the only universally accepted technique is by comparing the abscission scar of the rice glume base under a scanning electron microscope (Thompson 1996: 186). Wild rice has a smooth scar because of the shattering nature of wild species and therefore the non-shattering rachis of domestic rice has a rough scar on the spikelet base. This is a good method of identification because this is a key character of the change from a wild to a domestic species and therefore would be a useful indicator of this genetic transformation. However, this method becomes problematic when examining archaeobotanical assemblages because these particular remains are rarely found. In Indian assemblages, there is generally poor preservation of macro-remains and therefore the more delicate parts of the plant such as chaff do not seem to preserve well. The assemblages analyzed in this project have very little or no chaff and mostly contain fully cleaned grains of rice, and this seems to be consistent throughout Indian prehistoric sites. Hence, other ways of distinguishing wild and domestic species using the macro-remains that are commonly recovered (the grains and small husk fragments) have to be investigated.

There is also the issue of immature grains being used especially by gatherers and cultivators of wild rice. Immature grains of wild rice are harvested so that they can be collected before they shatter and are therefore lost. The scar of an immature rice spikelet will have a rough scar much like is seen on domestic rice spikelets. Therefore, this method may not be suitable for examining early farming sites and may in fact be misleading.

As well as examining macro-botanical remains, phytolith analysis has been conducted in this project, which means this data is also available for identification. Rice chaff phytoliths occur commonly in the majority of samples and therefore this supports the suggestion that the lack of macroscopic chaff remains is likely to be the result of preservation issues. Rice phytoliths from the leaves and the floral parts of the plant are used to identify rice to species or even sub-species (Zhao et al. 1998, Lu et al. 2002, Zheng et al. 2003). New methods using morphometrics are currently being used on archaeological assemblages from China (MacNeish & Libby 1995, Zhao 1998). Therefore, can these methods be used on Indian assemblages if developed for Chinese sites?

It is not going to be attempted here to review all the methods used for the identification of rice because as mentioned above Indian archaeological assemblages are limited by preservation problems and also there have previously been several large reviews, which cover all the issues for macro-remains and for micro-remains on pottery (Thompson 1996: 164-183, Ahn 1993: 53-131). In this review, the focus is put on a number of methods that are currently used routinely in archaeological investigations both on macro-remains and phytoliths. These are all morphometric techniques either measuring cleaned grains or double-peaked phytolith husk cells. Other phytolith identification methods used on leaf morphotypes are also reviewed here. All the phytolith methods used currently have not been reviewed together previously and compared on the same body of samples. An aspect that has never been explored previously is the comparison of macro-remains data with phytolith data. Will a modern study using both these types of methods on the same populations present the same results? Will they be complimentary methods or will the results conflict? Which will prove to be the best method for distinguishing wild from domestic species?

6.3.1 Measurement of caryopses or spikelets

Although this is a routine method of identification used by archaeobotanists, there is no standard method of measuring. Many cereals show a change in size after domestication and this method can be used to investigate this factor (Nesbitt 1997, Colledge 2001, Willcox 2004). This size change may not be an immediate consequence of domestication and may take many years to become apparent in archaeological remains. However, it is clear that there is great variation in the size of the rice grain and the spikelet today, especially in domestic rice, and therefore to use this characteristic a large comparative study is needed. There are great variations within and between biological populations and at different points in the crop processing sequence (Thompson 1996: 176). There are even variations between the size and shape of grains and spikelets on the same plant.

When dealing with archaeobotanical assemblages more variations also have to be considered. The state of preservation of the rice grains will potentially affect the grains dimensions. Most of the remains recovered are charred and this can cause shrinkage, which can also occur through desiccation. Water-logging has the opposite effect of plumping up the grains. While studies have been conducted of the charring effects on cereals (Hopf 1955, Renfrew 1973, Crawford 1983, Magid 1989, Boardman & Jones 1990, Nesbitt 1997, Viklund 1998, Fuller 1999), fewer include rice (Garton 1979, Lone et al. 1993). Garton (1979) carried out a study of the effects of charring on rice grains and considered a number of variables including temperature, rate of heating, and moisture content of grain. Garton concluded that the dimensions of the grain did not alter significantly. The species of the grain could be identified after charring however, the length and width of the grain did reduce. The only time the dimensions can not be used for identification is if there was visible distortion of the grain. Other studies on cereals have found that in general there is between a 10% and 20% reduction in the length and breath with generally somewhat more reduction in length leading to plumping (Fuller 1999). However, sometimes these dimensions can alter as much as 46% (Nesbitt 1997). More work needs to be conducted on the effects of different preservation states on the size and shape of grains so that this data can be used along with morphometrical identification methods.

Size difference in the grains can also occur due to premature harvesting and the imperfect state of grain development. Harvesting an immature crop is known to take place with wild species (Raju 1999, Kornel 2006: 49). This may interfere with the measurements taken of archaeobotanical assemblages. Ahn (1993) has suggested that the reduction in the thickness and weight of the grain are the only effects of premature harvesting. The grain usually reaches full length between five and seven days following pollination and the full width is achieved after the 15th or 16th day. However, not all of spikelets mature at the same time therefore some will not have reached full maturity on day 15. Hence, length and width dimensions could be used for identification purposes and the thickness should be used with caution since it matures last on approximately the 20th day (Matsuo & Hoshikawa 1993: 355-359) but it must also be remembered that some proportion of any crop will be immature because of the uneven ripening of the panicle.

Measuring errors is another problem that has to be considered when using morphometric methods. This does not only apply to this method but to the other techniques discussed below. Measuring the dimensions of grains or spikelets is not done uniformly. There are various methods used for measuring grains including: i) under a microscope using an eyepiece graticule; ii) an enlarged image; iii) using calipers. Most researchers do not say which method they use to measure the grains so can we compare the results? Ahn (1993: 110) conducted a repetitive test, which included repeating measurements himself using two different methods (microscope graticule and calipers), and also getting a student to carry out the same measurements. He found no significant error in the different measurements. However, it is best to use the same type of measurement method for all measurements to reduce any error and when presenting the data the method used should always be stated clearly.

There will also be error between researchers due to where the measurements are taken on the grain. When measuring spikelets, there is a difference of opinion as to whether the rachilla and sterile lemmas should be included or not. Garton (1979) has excluded the base of the sterile glume from the measurement but other researchers have included these parts (Ahn 1993: 110).

The thickness and width of spikelets and grains are also measured differently. Researcher can choose to take the measurement at the mid-point or the widest or thickest part of the grain. Therefore, these types of differences in measurements could produce significant errors and make it hard to compare work from different sources. It is clear that it is important to provide clear methods when presenting any measurement data so that measurements can be compared correctly.

These measurements are routinely used to identify rice species in Indian archaeobotanical reports. Vishnu-Mittre (1972, 1974) presented a calculation (Length/[Width x Thickness]) using measurements of modern grains as the basis of identifying ancient rice grains. This has also been used by other scholars (Constantini 1979, 1987, Saraswat 1986a, Saraswat et al. 1994, Chanchala 2000-2001). This calculation basically identifies domestic rice as being below 1.80 and wild rice species are above 2.20. The problem with using this method is there is no consideration of the wide variety of sizes and shapes of grains that are found in domestic varieties. Different figures have been presented by Savithri (1976) and Sharma (1983) for this calculation and therefore it is doubtful that this criterion can be used for identifications between rice species. In this project, a new study of the dimensions of modern rice species is being undertaken and this method will be further investigated with the new set of modern data.

6.3.2 Measuring bi-peaked tubercules on the rice husk

Another method that is used commonly in archaeological studies, especially in India, is examining the surface patterns of the fertile lemma and palea known as 'bi-peaked tubercules'. There are a number of different methods used for the examination and they can be applied to impressions of husks on pottery, which happens in the majority of studies in India, and also can be applied to actual preserved rice husks.

Chang (1976) was the first researcher to apply these techniques to archaeological samples. He used the SUMP (Susuki's Universal Micro-Printing) method developed by Katayama (1969). Chang (pers. comm. in Yen 1982:56) describes domestic rice as having regular cells in a squarish checkerboard pattern where as the wild species have irregular patterns of cell shape and arrangement. However, in the original study by Katayama (1969), he determines that there are no significant differences among the species of the Section Sativa and the differences are with other wild species outside this section. He recognised that domesticated rice could be distinguished from perennial wild rice by the shape of the tubercles but does not say there are differences in the cell arrangements. This means that the wild progenitors of domestic rice (*Oryza rufipogon* and *O. nivara*) have similar cell arrangements to *O. sativa* and therefore this criterion can not be used to determine wild from domestic species. It can only be used to determine the Sativa complex from other species complexes in the genus *Oryza*. This method could also be used for discriminating spikelets of *Oryza* from other genus in the tribe such as *Leersia* (Katayama 1969, Sharma 1983).

Chang also suggests that trichomes are not present in domestic species. Yen (1982) and Thompson (1996:183) point out that hairs are present on the husks of cultivars, although they may be absent on some cultivars, therefore this criterion is not accurate and can not be used for distinguishing wild from domestic species. There is also the issue of preservation when using this criterion on archaeological material as sometime these hairs may not survive.

Two studies focused on the tubercules have been carried out by Indian scholars but these are unpublished (Savithri 1976, Sharma 1983). Extracts of this work has been published in Thompson (1996:180-183) and she suggests that the identification criteria stated by these studies is still subjective and does not go any further to distinguish wild from domestic species. It is clear from the data and descriptions presented in Thompson (1996:180-183) from these studies that although the researcher may be familiar with these criteria themselves, it is hard for this data to be used by other researchers. Savithri's (1976) examination of the tubercule densities only proves the wide intraspecific variation and overlap familiar in wild and domestic species and is not diagnostic to species level as she suggests. It is again clear from these studies that the topography of the lemma and palea can not be used to securely identify wild from domestic rice species.

Unfortunately, these criteria for the examination of the husk are used routinely by many researchers on archaeological specimens. Vishnu-Mittre and his successors from Lucknow, India, regularly present the results of microtopography investigations of rice husks as evidence for identifying rice species (for examples see Vishnu-Mittre & Gupta 1968b, Chanchala 1991-1992, Saraswat 1993b). No methods have been published in their papers and also no quantitative support has been reported but it is clear that Chang's criteria are followed in most studies because of identifications of domestic rice from regular, checkerboard patterns of the husk. Therefore, any identification carried out using this method should be viewed with caution.

Archaeological studies add more confusion because the material may be distorted through charring or distortion may occur in the manufacturing process of pottery meaning rice husks impressions are misshapen. Experiments are needed to determine the extent to which such distortions are significant. There is also variation in the tubercules at different places in the rice husk, which needs to be considered as it is normally hard to determine which part of the husk the impression comes from. This variation over the rice husk is a key factor that hinders the ability to identify rice species and equally applies to phytolith studies.

Zhang (2002) has developed a method of measuring the shape of the bi-peaked tubercule on the rice husk. This is the same feature as measured by Zhao et al. (1998) but in the latter study phytoliths are measured. The Zhang (2002) method has been undertaken on modern rice husks which are not burnt to obtain phytoliths but are instead mounted on SEM stubs and measured while fresh. Although Zhang (2002) demonstrates that this method works to some extent there are clear problems with this study.

In the Zhang (2002) study 59 spikelets of modern *Oryza sativa* subsp *indica* including 14 varieties, 54 spikelets of modern *Oryza sativa* subsp *japonica* including 14 varieties, and 42 spikelets of wild rice (*Oryza rufipogon*) were measured in the study. The *Oryza rufipogon* may have included some *Oryza nivara* as this species is not recognised by Chinese taxonomists but may well occur in South China. In total 155 grains were measured. This is not a large enough study to establish a method of identification because there is great variation within and between rice species.

This study does not investigate any other wild rice species. The other rice species that should be included in this study is *Oryza nivara* as it is the other possible wild progenitor for domestic rice but this has not been included due to differences in taxonomy. The lack of wild rice investigated may be due to no other wild rice species occurring in the particular geographic area under investigation therefore this study may be specific just to that area although again *Oryza nivara* may be present but not differentiated from *Oryza rufipogon*. However, other wild species may also have similar tubercle shapes to the domestic species and therefore as many species should be investigated as possible so that this method can be used in any archaeological study not just those conducted in China.

The number of spikelets measured per population is very low. For the domestic rice, between 4 and 5 spikelets were measured per variety and it is not clear whether the *Oryza rufipogon* comes from one population or more than one. Therefore this study is not very representative.

The spikelets selected for the study were all mature samples and the measured area was always in the middle section of the husk. Although this would give the most comparable results, it is not necessarily what is going to be encountered in archaeological samples. The ancient grains may be immature or only the tip or end of the husk may be present. These variables need to be taken in to account in an identification study that is going to be used on archaeological specimens and it would not be possible with this study to tell where smaller charred husks or husk silica bodies come from.

The method does not state how many bi-peaked tubercles are measured per grain therefore it is hard to judge how representative the study is. A large number of tubercles (minimum of 15 to be representative) should be measured per husk because there will be variation even over a small area of the husk.

Although the Zhang (2002) method has limited application on archaeological samples, some of the techniques used are interesting and can be applied in different ways. The measurement of angles on the tubercle is another dimension that could be measured on double-peaked phytoliths (see figure 6.4). The peak angle and column angle (col angle) separated out all the rice species well in the original study. This measurement of angle is likely to be independent of size and relates more to the shape of the tubercle. This means that it may overcome some of the problems of variation over the husk if shape is a constant and it is only size that varies. These angles are measured on the double-peaked phytoliths in this project because there are no macroscopic husks present in the archaeological samples. Generally in Indian archaeological samples grains are found with no husks remaining. It will be interesting to see if these angle measurements have a similar affect on phytoliths to enable them to separate out the different rice species better than other measurements.

6.3.3 The use of phytoliths for identifying rice species

As discussed at the beginning of the chapter, the rice plant produces a number of different phytolith forms that can be used to identify it. Fan-shaped bulliforms and scooped bilobes are found in the leaf of all *Oryza* species. Double-peaked and single-peaked husk cells are present in the epidermal cells of the rice husks. However, similar phytoliths can also be found in some grasses and care needs to be taken when using these morphotypes to recognise rice species.

Using bulliforms for identification

Fujiwara and his team (Fujiwara 1993, Zheng et al. 2003a, 2003b) have developed a method for distinguishing between the subspecies of domesticated rice. The method involves taking a number of measurements of the keystone bulliforms and then applying discriminant function multivariate analysis to separate the subspecies. The original study for this method has only been published in Japanese and therefore it is hard to determine if it was carried out on an adequately sized and representative modern reference collection. It is also not clear if other grasses have been compared to the bulliforms from domestic rice or whether they have even been compared to wild rice species. If a full comparative study has not been conducted, there are fairly good reasons because this study was carried out in Japan, which does not have wild progenitors of rice. However, weedy rices and other grasses have similar bulliforms which need to be compared to determine if they interfere with the identification of domestic rice. Japan does have a number of grasses in its flora, which are in the Oryzeae tribe: *Leersia japonica*, *Leersia oryzoides*, *Chikusichloa aquatica*, and *Zizania latifolia* (Ohwi 1965).

Pearsall et al. (1995) has conducted a small study on the use of this method for distinguishing the wild from the domestic species of rice. They measured five species from the Oryzeae and Bambusineae tribes: *Oryza sativa* (two types), *Oryza minuta*, *Leersia oryzoides*, *Melocanna baccifera*, and *Phyllosta bambusoides*. As in Fujiwara's (1993) method, a series of measurements were taken on the keystone bulliforms: vertical length; horizontal length; lateral length; ratio of the base length and length of the non base portion (see figure 6.5). The measurements were put in to a multiple linear discriminant function analysis package, in this case SPSS, to analyse the data. From this analysis it was concluded that this method can not be used alone to identify rice archaeologically in regions where rice relatives exist. *Oryza sativa* was correctly assigned in to the correct group 52.33% of the time, which is suggested to be unsatisfactory. *Oryza minuta*, *Leersia oryzoides*, and *Melocanna baccifera* were misclassified as *Oryza sativa* 25% of the time.

Although the Pearsall team's study shows that the measurements they have taken can not be securely used to determine wild from domestic rice, this is not a definitive study.

The sample size was small and a larger study is really needed to determine precisely how good this method is for distinguishing different Oryzeae taxa, *Oryza sativa* subspecies, or even wild from domestic rice. This method may still be utilised in certain historical/geographical contexts.

The Fujiwara method has been used in China to determine between *indica* and *japonica* domestic rice (Zheng et al 2003a, 2003b) but in these studies it was not used to identify the presence of domestic rice rather it was simply assumed that all the bulliforms measured were domesticated. Macroscopic remains are used to identify domestic rice and then the phytolith analysis is carried out assuming all the keystone bulliforms, of a particular shape, are domestic rice. There are two problems with this, firstly the macroscopic remains may not be identified properly and secondly they have not considered that wild rices and other grasses will interfere with the measurement of bulliforms. More care needs to be taken when applying this method to archaeological studies. Although, given genetic evidence for separate origins of *indica* and *japonica* subspecies, we could predict on phylogenetic grounds that *Oryza rufipogon* bulliforms would resemble that of *japonica* and *Oryza nivara* type of *indica*. This would not help in the distinction between wild and domestic species.

A recent study by Lu et al. (2002) suggests that keystone bulliforms can be identified as *Oryza sativa* by the scale-like decorations on the lateral side of the bulliforms (see figure 6.6). This is a promising study, which although again is not very large, does show some interesting results that can be applied to archaeological studies. Seven wild grasses were compared to six cultivated rice species. The wild grasses included in the study are *Oryza perennis*, *O. punctata*, *O. minuta*, *Leersia oryzoides*, *L .hexandra*, *Zizania caduciflora*, *Z .miliacea*. *Oryza perennis* is also known as *O. rufipogon* but could also include *O. nivara* and weedy *O. spontanea* hybrid types if they do not separate these species. It is clear from this study that *O. perennis* has the closest characteristics to *O. sativa*, which is what would be expected. There is actually some overlap in the number of scale decorations between these species. Lu et al. (2002: 381) have concluded that *O. sativa* commonly has 8 to 14 scales, while wild rice species have less than 9. Therefore, domestic rice can be identified when more than 9 scales are present on the bulliforms. From the results presented in the paper (Lu et al 2002), the *Oryza* genus could be identified by more than 6 scales.

Although, this is an interesting study, at this point it can not be used securely to identify domestic rice because the closest relatives have not been tested separately. The distinction made in this study may in fact just separate *indica* and *O. nivara* from *japonica* and *O. rufipogon*. It is also apparent that changes in the different *Oryza* bulliforms track post Last Glacial Maximum climate change therefore it is more likely to be showing migrations of wild rice than a shift from wild to domestic rice. Only with further modern studies will this method be proved or disproved. Unfortunately none of the above methods using bulliforms can be tested in this project on new modern material because insufficient samples of leaf specimens of rice were available. However, the Lu et al. (2002) method is going to be conducted on some of the archaeological samples to assess whether it matches with the results from other methods and whether it is a simple method to use.

Measurement of double-peaked husk cell phytoliths

A method of measuring double-peaked husk cells has been developed by Pearsall and her team (Pearsall et al. 1995, Zhao et al. 1998, Zhao 1996), which is now being routinely used on archaeological samples from China (Zhao 1996, Zhao 1998). To develop this method a substantial study was conducted, which forms a representative sample for all the rice species. In the study they used 27 accessions of domestic rice from China and 79 specimens of wild rice species from South and Southeast Asia: i) *Oryza granulata* Nees et Arn. (3 specimens); ii) *Oryza longiglumis* Jansen (5); iii) *Oryza meyeriana* Baill. (4); iv) *Oryza ridleyi* Hook.f. (9); v) *Oryza minuta* J S Presl. (9); vi) *Oryza officinalis* Wall. (16); vii) *Oryza nivara* Sharma et Shastry (15); viii) *Oryza rufipogon* Griff. (11); ix) *Oryza sativa var. spontanea* (7). All the specimens were supplied by IRRI and therefore it can be assumed that they are identified correctly. Five measurements were taken on 25 individual double-peaked glume cells per slide (see figure 6.4 for diagram of measurements taken).

It is not clearly stated in the method whether phytoliths were extracted from just one husk or a number of husks. If it is just one husk, then can this be representative for the population? The answer to this is probably not but it will demonstrate the variation in the dimensions of this cell on one husk.

Discriminant analysis was used to separate the results in to three groups: wild, domestic, and indeterminate. Although they have been able to show that they can make the measurements separate in to these three groups, this method of analysis seem to be forcing the data. In the 1995 paper (Pearsall et al. 1995), they comment that there is a large amount of variation within each species making it impossible to separate the species on means and ranges. The authors also go on to prove that cluster analysis does not separate the data in to clear groups. *O. rufipogon* is in one group and the domestic species as well as the other wild rice's are in the other group. It is a shame that they have not demonstrated the use of simple ratios before going on to use multivariate methods because this lack of initial separation does not bode well for further analysis. If this method is to work properly then there should be some separation visible before having to resort to statistical packages to make separations in to species (Whallon 1987, Baxter 2003: 16).

It is apparent from the above review of methods that an independent study needs to be conducted of these identification methods to determine if they can be used on archaeological samples or on specimens from another region such as India. The first step is to independently assess a couple of the methods and this is done below.

6.4 The present study of the identification methods of rice

In this project a study of rice identification methods is being undertaken to compare three methods using the same rice specimens for each method. The methods that are being used are: standard length/width/thickness measurements of rice caryopses; the measurement of double-peaked husk phytoliths using Zhao et al. (1998) method; and the measurement of double-peaked husk phytoliths by adapting Zhang method of measuring bi peaked tubercles.

87 modern populations of rice have been collected which include both domestic and wild species as well as some hybrids. The species that are being measured are *Oryza sativa* (*indica* and *japonica*), *Oryza nivara*, *Oryza rufipogon*, *Oryza spontanea*, *Oryza officinalis*, *Oryza granulata*, and *Oryza punctata*. Figure 6.7 shows a table of the number of populations measured per rice species. A list of the populations used and detailed information about their origin can be found in figure 6.8. The majority of the samples have been provided by the International Rice Research Institute in Manila, Philippines. The rest of the samples were either collected by the author during fieldwork or come from the collections held at the Institute of Archaeology, London.

6.4.1 Measuring the caryopsis

It was decided that grains without their husks would be measured because this is the state in which rice is usually encountered in Indian archaeological samples. All of the 87 populations were de-husked and the caryopses were measured using a binocular microscope fitted with an eyepiece graticule. The measurements were taken at x10 magnification and the graticule was calibrated with a ruler at the beginning of each measuring session. The grains were lined up horizontally on paper using plastercine so that a minimum amount of movement would occur making measurement more efficient. Fifteen grains from each population were measured. A drawing of how the measurements were taken on the grain can be seen in figure 6.9. The length was taken from the tip to the base of the grain, obviously as the whole spikelet is not being measured there is not a problem with including or not including the base of the sterile glume. The width and thickness were always measured at the widest or thickest points of the grain.

6.4.2 Measuring double-peaked husk cells

A subset of thirty seven populations was selected for the two phytolith studies. A smaller number of populations were selected due to time constraints but it was felt that this would still provide a good study for comparison with the macroscopic data. From the selected populations all 15 husks, that had previously been taken from the measured grains, were ashed to provide an average for the population. The husks were first cleaned by washing them in a petri dish with distilled water. They were then air dried and cut in to small pieces. These pieces were then placed in small, clean ceramic boats and put in to a cold furnace. The furnace was heated up to 500°C and the samples were left in the furnace from between two and three hours. When the husks had turned white they were determined to be ashed and the furnace was turned off. The samples were removed when the furnace was cool. They were then transferred in to clean glass tubes for storage.

Before mounting, the ashed husks were broken up gently with a clean spatula to hopefully break up some of the multi-celled panels. If there are too many multi-celled panels and they are too large then the double-peaked husk cells do not face the right way for measuring. These phytoliths are hard to turn and therefore a moveable mountant is not necessary. It was found that enough husk cells were facing the right way for measuring so any attempts to rotate the phytoliths were not needed. Therefore half of the ash produced was mounted on to the slide using the mountant Entellan. This is a good mountant for measuring even though it does dry solid after about a week but it will stay clear for many years. Canada balsam has the disadvantage of turning yellow after a few years and therefore is a less good choice for reference slides. Entellan also has the advantage that it is thinner than Canada balsam and therefore the phytoliths all sink to the bottom of the slide so that all the phytoliths can be viewed on the same plane when measuring or counting. This is not the case with Canada balsam which tends to have phytoliths on different levels in the slide making it harder to work on the slide.

For both phytolith methods of measuring, 25 phytoliths were measured per slide. It was decided to take photographs of all the phytoliths and then measure off the photographs because an eyepiece graticule with fine divisions was not available. All photographs were taken using a trinocular transmitted light microscope and a Nikon digital camera. A photograph was taken of a fine slide graticule at x 500 and this was used to get the actual measurements in microns. The co-ordinates of every phytolith photographed were taken so that they could be examined again if need be. An imaging package could be used to do the measuring for this method but in this case each photo was printed in Photoshop and the measurements were taken using calipers and then reading the measurement off the photograph of the slide graticule. A protractor was used on the photographs for measuring the angles needed in the Zhang method. The measurements that have been taken can be seen in figure 6.10.

There are always going to be some errors when taking measurements but these should be controlled as much as possible. When using this method, it is sometimes hard to see where to take the measurement at the base of the cell (MW) as the bottom of the cell was sometimes obscured. Taking measurements from photographs was probably harder than down a microscope but if the bottom of the cell was not clear then the phytolith was re-examined on the slide. When measuring began, a number of phytoliths were measured several times to check that measuring was consistent and it was found to be sufficiently consistent. Advantages of taking measurements from photographs are that it was a quick way of measuring and there is a permanent record of the phytoliths measured that can be referred back to.

6.5 Results of the modern study of identification methods for rice

The results of this study will be assessed at two levels. Whether the different species can be distinguished from one another and whether wild and domestic species can be recognised. In a sense it is the later issue that is most important for archaeological application but also knowing the exact species present especially wild can also have implications as to why the wild plant was being exploited and if it is likely that there is a progression from one of the wild progenitors to the domestic species.

6.5.1 Identification using measurements of the caryopsis

Comparing the basic measurements

Looking at the results from all of the different rice species that were measured shows that there is a lot of overlap in the size and shape of the grains. This is clearly shown by figure 6.11, which is a table of the ranges and averages for each species. *Oryza sativa* has the largest variation in measurements particularly in the length. The measurements for the other rice species tend to vary slightly less than those from domestic rice but all the measurements overlap with each other to some extent.

However, some species can be separated as can be seen in figures 6.12 to 6.14, which show graphs that compare length, width, and thickness measurements of each rice species. The comparison of length with width and length with thickness shows a group that is shorter and thinner than the other species. This group includes the wild species *Oryza officinalis*, *O. granulata*, and *O. punctata*. Some of the *O. sativa* grains overlap with the larger grains of these species but generally the former wild species are much smaller than the other rice grains in the study.

There is also some separation seen in *O. sativa*, however this species has a very wide variety of measurements overall. There are some of these grains that are shorter and some that are longer. Some of this separation is caused by the different varieties of domestic rice. This is demonstrated in figure 6.15, which shows the *japonica* variety grains to be shorter than the majority of the *indica* grains. There is a lot of variety in the indica type grains and this does overlap to some extent with *japonica*.

There also seems to be a general pattern that *O. sativa* grains are the thickest and widest out of all of the grains measured although this only occurs in a small number of the grains. This can be seen when these measurements are each compared to the length as in figures 6.12 and 6.13. Comparison of the width and thickness measurements for all species shows the most overlap and therefore this comparison is the least helpful for distinguishing the different species. The majority of the domestic rice grains overlap predominantly with *O. nivara*. This species is generally larger than *O. rufipogon* but there is again a lot of overlap between the two species. *O. spontanea* also overlaps with both species but is more like *O. nivara* in its size and shape than *O. rufipogon*.

The hybrids that have been measured show, as might be expected, that they overlap with *O. sativa*, *O. rufipogon*, *O. nivara*, and *O. spontanea*. This was really done to demonstrate that early populations of cultivars, which are likely to have many hybrids in them, make identifications even harder for archaeological material.

These results demonstrate there is just too much variation in the domestic rice to allow identification using measurements of the grain. There is also a fair amount of variation in wild species especially *O. nivara* and *O. rufipogon* causing considerable overlap between these two species and with others. It might be possible to distinguish *japonica* varieties but a larger study needs to be conducted using more *japonica* grains to confirm this initial finding. However, this would not have much effect on Indian archaeological sites as indica varieties are the most likely early cultivars and it is therefore not surprising that the indica grains overlap predominantly with *O. nivara*. The only real possibility of identifying domestic rice is from very thick (over 2.2 mm) and very wide (over 3.1) grains but this also should only be used with caution because charring may either expand archaeological grains or shrink them meaning that this criterion is hard to apply unless the ancient measurements are adjusted. A distinction that is possible to some extent is the separation of the Sativa complex from the other wild rice complexes. This may be useful for archaeological studies but still does not distinguish the wild progenitors from the domestic species.

Ratios and calculations of the grain measurements

Looking at ratios such as length/width again shows that there is far too much variation in the domestic species to allow identification from wild species. Figure 6.16 shows the percentage of occurrence for the L/W ratio of rice species in certain categories. *O. sativa* occurs in all of the categories and therefore overlaps with all of the other rice species.

Another calculation that is used by archaeobotanists is L/(W x T) (Vishnu-Mittre 1972, 1974). This has already been suggested to have problems with it because it does not account for the huge variety in domestic rice (Thompson 1996). This study shows that the categories used by Vishnu-Mittre (1972, 1974) to identify rice species are inaccurate (see figure 6.17). The majority of *O. sativa* grains do have values below 1.8 but some have larger values. However, the main problem is that *O. nivara* also shows the majority of grains with a value below 1.8. *O. spontanea*, *O. granulata*, and *O. officinalis* also have the majority of grain values below 1.8. *O. rufipogon* shows higher values with none of the grains being below 1.8. Therefore this is not a method that can be used to distinguish between different species of rice.

Multivariate analysis for grain measurements

The multivariate analysis, in this case discriminate analysis using Minitab, of all of the species and hybrids measured matches the initial findings suggested above (see figure 6.18 for example of results from multivariate analysis). Comparing length, width, and thickness measurements to achieve correct classification has been most successful for *O. granulata*, *O. officinalis*, and *O. punctata*. These species were also found to stand out using more simple methods of analysis. About 52% of the *O. sativa* grains were classified in to the correct group and *O. nivara* had a much lower success of correct classification (28%).

By just comparing *O. sativa* and its wild progenitors, *O. nivara* and *O. rufipogon*, there is slightly more chance of getting the correct classification. *O. rufipogon* is classified correctly 80% of the time but the other two species are only classified correctly about 65% of the time. However, this again demonstrates that there is just too much overlap in the shape and size of these species to allow accurate identification using this method.

Comparing archaeological grain measurements

Even though it has been demonstrated above that it is very hard to identify rice grains to species level using grain measurements, a comparison of archaeological measurements with the modern study will be made to see if any implications can be made as to their identifications. Generally the archaeological grains are very small in comparison to the modern rice grains. This could mean a number of things: they could be predominantly small wild species; or there may have been a considerable amount of shrinkage due to carbonisation; there is also the possibility that they may be immature grains. All of their dimensions have reduced and therefore shrinkage definitely plays a part in their small size. With some adjustment for this shrinkage it can be clearly seen that the archaeological grains start to overlap with the larger wild and domestic modern grains although some grains are still very small (see figure 6.19). Some of the archaeological grains, particularly the ones from Golbai Sasan are close to the size of domestic grains. This means that there are possibly three groups of archaeological rice grains: mature Sativa complex grains, immature Sativa complex grains, and small wild rice grains such as *O. granulata*.

The likelihood of immaturity can be investigated by comparing the archaeological measurements to graphs showing the measurements of maturing grains (see figures 6.20 and 6.21). Only a graph for *japonica* is available so the grains from India, which are likely to be *indica* would not be as wide and may also be slightly longer in length. However, this can give some idea of the whether there are any potential immature grains in the archaeological assemblage. Figure 6.21 compares the archaeological measurements to modern width and length when maturing. It is clear, again, that the archaeological grains are smaller than the modern measurements. The widths are smaller and to some extent this is expected because these are likely to be *indica* rather than *japonica*. The lengths are considerably shorter and therefore some of the grains may well be immature. Although, there is the problem of equifinality using this method because the smaller rice species and also shrinkage could bring these grains in to the immature range. The grains that are very small, such as some of the grains from Golbai Sasan and Mahagara, are likely to be wild whether they are the smaller rice species or immature *O. nivara*.

6.5.2 Identification using double-peaked husk phytolith

Comparing the basic measurements

By comparing the individual double-peaked husk measurements to each other as well as using the population averages there is a large amount of overlap as had been found with the grain measurements. A table of the ranges and averages for each rice species can be found in figure 6.22. This shows there is a large range for most of the measurements taken on the double-peaked husk especially the TW and MW measurement. It is also clear from these ranges that there is considerable overlap particularly in the measurements of *Oryza sativa*, *Oryza nivara*, and *Oryza rufipogon*.

Examining the averages showed some of the smaller wild species do seem to separate using the TW measurement. *Oryza granulata* has a small average TW and *Oryza officinalis* has a larger TW than the other species (see figures 6.23 and 6.24). However, comparing the individual measurements indicates that this separation is not as straight-forward and there is still considerable overlap with the TW measurements of other species.

The other rice species vary enormously in the size and shape of their double-peaked husk cells meaning that there is a huge amount of overlap. There seems to be no way of separating the domestic rice from the wild species using basic comparisons of the measurements.

Multivariate analysis of the phytolith measurements

Multivariate analysis was conducted using a computer program called Minitab and this allowed discriminant analysis to be applied to the data (figures 6.25 and 6.26 show examples of results for multivariate analysis). A number of different methods were used including quadratic and linear discriminant analysis, and cross-validation was also tried to see if it produced better results. These methods were used to compare all of the measurements taken in this study. Classifying each species in to its correct group only had very little success with this analysis. All of the different methods have put approximately 40% of each species in the correct group. This means that 60% would be identified wrongly if using these measurements. It is therefore clear that this method can not be used to determine the double-peaked husk cells to species level identifications.

Putting the data in to two categories, wild and domestic, as has been done by Zhao et al. (1998) did improve the percentage of correct classifications. The results for this new study, if we use just the five measurements, are slightly lower percentages to the original study giving 58% correct classifications for domestic rice (79% in previous study) and 60% for wild rice (71%). However, there are still far too many double-peaked husk cells that are misclassified and therefore there would be too much error to use this method for identification of archaeological specimens. Using all of the seven measurements taken in this study, the correct classification percentage rises for domestic rice to 72% and 69% for wild rice (see figure 6.26). This is still too low to be used for identification purposes.

Zhao et al. (1998) go further to manipulate the data to try to reduce the errors of misclassification but this does not seem to be an appropriate use of the data. This has been done by adjusting prior probabilities before using discriminant analysis to minimize the errors. They have created three groups by doing this: domestic rice, indeterminate, and wild rice. This has been conducted because of the overlap between domestic and wild rice. They created equations to group data into these three groups but the results in this project did not come out into the correct groups using these equations. Therefore, it can not be concluded that the equations work to identify rice as has been stated in their paper (Zhao et al. 1998). It is clear that there is some polarisation between the domestic rice and all of the wild rice species. However, this is not enough to allow accurate identification to species level.

Comparing archaeological measurements

Figure 6.27 shows a graph comparing the archaeological double-peaked husk measurements with the modern data. There is a great deal of variation in the archaeological measurements, which is much the same as the pattern found with the modern specimens. There is too much variation and no clear groupings whether by site or by period. Therefore, it is not possible to identify the ancient rice remains using this method.

The chips on the rice bulliforms have also been counted for the archaeological phytoliths. Graphs showing the results can be found in figures 6.28 and 6.29. The categories that the number of chips have been divided in to are wild rice/*japonica*, intermediate rice, and domestic (*indica*)/*nivara* rice. Wild rice could in fact also include domestic *japonica* rice and the domestic rice category could include *Oryza nivara*. This is because the original study (Lu et al. 2002) did not investigate all of the separate species that could be found in India. The intermediate category incorporates bulliforms that have eight chips as this can occur in the wild and the domestic species. Therefore, because of the problems of identification there are rather mixed results and it is hard to interpret what they mean. At Koldihwa and Mahagara, the majority of bulliforms are in the domestic/*nivara* category. This means that they are all domestic or *Oryza nivara*, which is not particularly helpful. At Gopalpur and Golbai Sasan, there is more of a mix of all three categories but there is no pattern emerging for these changes in categories. What is interesting is that there is only one bulliforms that has very few chips (four chips from Gopalpur sample 14) and therefore the majority of the bulliforms are likely to be of the *Oryza* genus. More work is needed to on this bulliform method to allow it to be used accurately on archaeological material.

6.6 Conclusions of the rice identification study

It is clear from this new study of rice identification methods that it is hard to identify any rice grain or husk phytolith to species level. The measurements taken of grains and also double-peaked husk cells demonstrate that the majority of rice species have large variations in size and shape making them hard to identify. Using rice grains there is the potential to separate some of the smaller wild species such as *O. officinalis*, *O. granulata*, and *O. punctata*. It is interesting is the presence of these species can be suggested because they can be found as crop weeds and are therefore ecological indicators of cultivation. They suggest cultivation without the presence of standing water and *O. officinalis* is found in a similar habitat to *O. nivara*. *O. granulata* comes from more forested areas.

However, this is not very useful for addressing the issue of separating domestic rice from the wild rice species. There is some possibility of distinguishing domestic rice because it had the thickest (over 2.2mm) and widest (over 3.1mm) measurements but only a few grains were this large. In the majority of cases this will not work with archaeological grains because these large grains only appear to be rare in any population and also the shrinkage from carbonisation will adjust these measurements although adding 20% routinely to archaeological specimens may help to overcome this problem. It may be possible, therefore, to separate the rice grains in to three groups; mature Sativa complex grains, immature Sativa complex grains, and small wild rice grains.

There seems to be even more overlap with the measurements taken of the double-peaked husk cells particularly of *O. sativa*, *O. nivara*, and *O. rufipogon*. Again, there are a few of the smaller wild species, *O. granulata* and *O. officinalis*, that could be separated using the averages of the TW measurement. However, even by using the multivariate analysis, none of these species could be separated to a satisfactory level to allow identification.

At present, this study suggests that there is more potential for using rice grain measurements than husk phytoliths although neither method is completely successful for identifying all of the rice species. Husk phytoliths can not be used to identify domestic rice and there is only a very small potential in using rice grains to identify domestic rice. More work needs to be conducted on other phytolith methods of identification such as the methods of measuring bulliforms from rice leaves and counting the chips to determine if these are accurate methods or not. Unfortunately, identifying rice to species level is still extremely problematic. It may be that this is never possible and therefore studies that investigate the domestication of this crop have to be approached more laterally such as looking for changes in weed flora to suggest cultivation and also trying to identify immature versus mature harvesting of rice, which will in turn identify the change to the domestic species. It has been shown here that some of the archaeological rice found in this project is potentially immature although this is complicated by the shrinkage due to carbonisation and also small wild rice species. More work is needed to look at alternative ways to identify the start and development of rice cultivation.

Chapter 7

Results of macro-botanical and phytolith analysis

This chapter presents and analyses the results of the new archaeobotanical investigations conducted in this thesis. The macro-botanical remains are examined here including confirmation of identifications of the material and the presentation of raw data, which is subjected to both qualitative and quantitative analysis. The phytolith data is examined including calculation of relative frequencies and absolute densities for each morphotype, and the comparison of different morphotypes using ratios. Both the analyses of the macro-botanical and phytolith data will concentrate on the economic plants and try to draw out patterns of crop processing and potential agricultural systems. The last section of the chapter will draw together patterns found in both methods of analysis and present similarities and differences found in both the datasets.

7.1 Macro-botanical results

All of the figures in this chapter are colour coded to the site and then in this particular section on macro-botanical remains each plant type has a different pattern. The colours are as follows: Koldihwa – red; Mahagara – green; Chopani Mando – blue; Gopalpur – purple; Golbai Sasan – yellow; Bajpur – turquoise, Malakhoja – maroon, Banabasa – pink; published sites – orange. However, the site and sample numbers will also be stated on all of the figures. For the macro-remains, the different plant types are also distinguished by patterns. On the first set of diagrams with plant types these patterns will be shown in a key.

7.1.1 Identifications and preservation issues

There are a number of seeds, which are particularly challenging to identify; rice, some Indian pulses, and small millets. The identification of rice has been thoroughly dealt with in chapter six and it was concluded that it is very hard to identify rice to species level. This is particularly true of distinguishing the wild progenitors from domestic rice. The archaeological material in this project, therefore, has not been determined to be either wild or domestic using measurements. However, there is the potential that some of the grains are immature because of their small size and therefore some grains are likely to be wild. There are potentially three groups of rice grains in the archaeological assemblages in this project: mature Sativa complex rice grains, immature Sativa complex rice grains, and small wild rice species such as *O. granulata* or *O. punctata*.

Vigna mungo and *Vigna radiata* are difficult to distinguish from each other and therefore morphometrics and the examination of the testa cell pattern has been used to make species identifications. *Vigna mungo/radiata* seeds were only found at Mahagara, Koldihwa, and Golbai Sasan. Two whole *Vigna* sp. seeds were found at Golbai Sasan (sample 3), which had clear testa patterns. They revealed rows of long and thin rectangular cells consistent with that of *Vigna radiata* (Fuller 2002a: 283) and they are also the only *Vigna* sp. seeds that had intact testas. The presence of the testa may affect the measurements as it has been found that if the testa remains intact then it limits the shrinking caused by charring (Jupe 2003). This is demonstrated in the following graphs, which clearly show these two particular seeds to be larger in size than the other testa-less *Vigna* specimens in the same sample.

Measurements of the whole seeds and cotyledons have been taken of the length, width, thickness, and plumule length. Two types of graphs can be used to try to separate these two species and also potentially the wild and domestic species; length vs width, and length vs plumule/length. Two graphs (figures 7.1 and 7.2) show the length and width measurements of modern domestic and wild *Vigna mungo* and *Vigna radiata* and the second graph is adjusted for 20% shrinkage due to charring. On figure 7.2 a cut off line is indicted to show the difference in measurements between the wild and modern enlarged domestic species and this will be used to determine seed identification in this project with a certain degree of discretion. Figure 7.3 shows a graph of the length and width measurement separation of these *Vigna* species in all of the sites examined. The two whole *Vigna* specimens with testas are clearly in the domestic range for these species. The other *Vigna* specimens are all cotyledons with no testas and fall within the wild range. However, they probably need to be adjusted to a greater extent for shrinkage because of their lack of testa and this may be the reason for their smaller size especially the ones that are particularly small. It is also likely that if these seeds are domestic, they are towards the lower size end of the modern domestic population measured because any significant change in size from the wild form may still not have occurred at this time. Therefore, size may not be a useful criterion, in this particular case, to identify domestication.

To distinguish between *Vigna radiata* and *Vigna mungo*, measurements of the cotyledons are used. Generally, for *Vigna mungo* the plumule length/length ratio is smaller than that of *Vigna radiata* (Fuller 2002a). Figure 7.4 shows a graph of the archaeological measurements comparing them to modern measurements. There was not a great deal of cotyledons available for measurement but this analysis gives some idea of what is present in the samples. The majority of the specimens are in the *Vigna mungo* range but some are on the border of the two species and therefore it is best to conclude that both of these species are present. Mahagara definitely has both species present and the Golbai Sasan cotyledons could be either species, although we have evidence of testa pattern that points to

Vigna radiata while results on other specimens suggest *Vigna mungo*. Koldihwa could just have *Vigna mungo* present.

The first challenge that was encountered when examining the millets present in the samples was whether they were archaeological or modern intrusions. Particularly in the samples from the Belan River Valley, there were a lot of modern seeds including partly blackened millets, which suggests a process of blackening of recent intrusive material. Some of these millets were fully blackened and appear charred, which suggest that they are ancient although very well preserved. What should be noted is that the grains of *Brachiaria ramosa* and *Setaria verticillata* that had their husks on and appeared to be very well preserved clearly show husk patterns consistent with these taxa. Those that were partly blackened were not counted but if they were fully charred then they were counted as being archaeological. However, these still may be modern and therefore they will not be included in any data analysis of the sites. In the same samples, these species did occur as fully charred and more ancient looking caryopses therefore these grains will be included in the analyses that follow. These grains were identified by the length of the embryo and the general size and shape of the caryopses as has been explained in chapter five.

Generally the preservation of the material from the Belan River Valley sites was worse than the material from the Orissan coastal sites. The quantity of material is less and the preservation state of the seeds in general is worse. At Golbai Sasan and Gopalpur, there were some very well preserved macro-botanical remains (whole pulses and rice) but there was also a high degree of fragmentation especially of pulses. The upland sites of Orissa and Chopani-Mando had very little or no macro-botanical remains. This is likely to be due to the type of occupation at these sites although at Chopani-Mando this could result from the generally poor preservation conditions in this area, as is evident also at the nearby sites of Mahagara and Koldihwa.

7.1.2 Results from Uttar Pradesh

Density of plant material

Overall, the amount of charred material recovered from the Gangetic sites is disappointing. All of the sites only produced a small amount of macro-botanical material especially Chopani-Mando. For the raw data tables see appendices 7.1, 7.2, and 7.3. As suggested above this is probably a result of preservation issues as the fluctuating wet, dry, and hot climate is not favourable for organic preservation. The density of the flotation samples per litre of sediment can be seen in the raw data tables (appendices 7.1 to 7.3). This reveals that the densities are low in all of the samples. Densities range from 9.25ml (KDW 3) to 0.15ml of charred remains per litre (CPM 69 and 71). Even from Koldihwa and Mahagara there are very low densities in some samples. Therefore the phytolith analyses may reveal further information not found in the macro-botanical data set. The low density of charred material does affect the amount of data analysis that can be used particularly for the results from Chopani Mando. Therefore during the analysis of the data no multivariate methods will by used and the data will be subjected to qualitative and simple quantitative statistical methods.

Presence/absence and ubiquity values of plant taxa

As can be seen in figure 7.5, the only plant remains present at Chopani Mando are small millets and a few weed seeds (see appendix 7.4 for ubiquity value table). These two plant types occur in 15% of the samples from Chopani Mando. The millets include the possibly modern *Brachiaria ramosa* and *Setaria verticillata*. There is also one fragment of indeterminate Gramineae, which could be a large cereal grain but was too badly preserved to identify. Therefore, there is no clear evidence of agricultural remains from these samples. The evidence is too poor to conduct further analysis hence the data from Chopani Mando will not be included in any of the analysis below. Phytolith analysis may reveal whether the lack of macro-botanical remains at this site was due to preservation problems or a result of none or little organic input in to the site.

At Koldihwa and Mahagara, the remains are still poor but there is evidence of greater organic deposition. A graph comparing the ubiquity values from all the Belan Valley sites can be found in figure 7.6. This graph demonstrates that Koldihwa and Mahagara have a wide range of different plant types present in the samples. All of the common agricultural plant types are represented: pulses, large cereal grains, small cereal grains, and fruits. At Mahagara, rice is the dominant cereal, which is present in 72% of the samples. After rice, pulses and small millets are the next most commonly occurring plant types found in 63% and 56% of samples. *Vigna* sp. is by far the most common pulse occurring in 44% of the samples. Wheat and barley have low occurrences in the Mahagara samples (3% & 22%). Weeds are fairly common (34%) although no single weed occurs in more than 9% of samples. *Ziziphus* sp. only occurs in few samples (9%) and some parenchyma is also present (9%).

Koldihwa has similar plant types present to those found in samples from Mahagara. The most dominant plant types are pulses (60%) and again *Vigna* sp. is the most common (45%). The next most commonly occurring plant type is small millets (50%) with *Setaria verticillata* occurring in 30% of the samples. Rice occurs in 40% of the samples, which is less than at Mahagara. Barley and wheat are again not as common as rice (25% and 10%) but are more commonly found at Koldihwa than at Mahagara. Weeds and *Ziziphus* sp. are also more common at Koldihwa (40% and 30%). No parenchyma is present in the samples from Koldihwa.

Comparison of new data with presence/absence and ubiquity values from other North Indian Prehistoric sites

The published archaeobotanical data from the North Indian Prehistoric sites is not presented as raw data and therefore only ubiquity values can be calculated for these sites. See appendix 4.1 for a table of the published data for North Indian Prehistoric sites. In general, there is a lot of similarity between the presence of plant types at Mahagara and Koldihwa compared to the published sites. The main large cereals of rice, barley and wheat are all present. Summer and winter pulses are present at both the published sites and the newly analysed sites but sites such as Malhar, Narhan, and Senuwar have a greater variety of pulses than at Mahagara and Koldihwa with additional species such as *Cicer arietinum* and *Macrotyloma uniflorum,* which possibly suggests the late adoption of additional pulse species in this region. The published sites also have more oil plants present as well as the presence of melons and cucumber, which do not occur at all at the newly analysed sites however these seem to occur in the later phases of sites or later dated sites. These sites also generally have larger sample sizes and therefore may be more likely to produce a larger variety of plant material.

As discussed in chapter four, there are only a few sites that have been analysed so far that fall in to a similar date range to the samples analysed in this project and even fewer of these can be used for calculating ubiquity values: Hulaskera, Manjhi, Narhan, Malhar, and Senuwar. See appendix 7.5 for a table of ubiquity values from these published sites. Of these sites, Malhar and Senuwar are the most relevant because they have similar sequences of deposits and the dating of these sites falls closest to Koldihwa and Mahagara. All of the published sites contained all the plant types except for Hulaskera, which did not have fruits or wheat present. This may have been because of the low sample size at this site compared to the others. Manjhi also has very small sample size (overall 4 samples) and this may account for the high occurrence of plant material in the samples. At the other sites, there is a fairly similar occurrence of the plant types. Pulses, barley, and rice occur most frequently. Weeds also commonly occur in samples from Narhan and Malhar. Wheat, small millets, and fruits are less common, although wheat does occur in 40% of the samples from Narhan.

Figure 7.7 compares the ubiquity values for the Mahagara and Koldihwa with those from the published North Indian sites. There does appear to be fairly similar occurrences of the plant types in the samples from these sites. Pulses and rice are most common although small millets are also common at Mahagara and Koldihwa occurring in 50% and 56% of samples compared to 30% and 25% at Malhar and Senuwar. At Malhar there is a very high occurrence of pulses being present in 75% of samples and lentils are most common of the pulses. Barley and wheat are less frequently found than rice and pulses at all of the sites. Weeds are also fairly common at most of the sites except Senuwar where they only occur in 18% of the samples. Fruits are present at all of the sites and are most common at Koldihwa (30%).

Relative frequency of plant types

To examine the changes in the relative frequencies of different plant taxa the results of the samples have been combined for each level. There are two samples per stratigraphic layer for Koldihwa and Mahagara. Koldihwa has also been split in to the two separate sections that were sampled; Z1 and Y1.

At Mahagara (see figure 7.8), rice and indeterminate Gramineae are the only remains present in the lowest level of the section (level 17). Rice is consistently present from the very beginning of the section right up until level 5 in varying amounts and always represents a substantial part of the level. In the next level up there is a sharp change with pulses, barley, and small millets being present along with the previous two plant types.

Pulses represent a large part of samples from this level (47%). Pulses are present from level 16 to level 6 and range from 55% (level 12) to 14% (level 6) in the levels. Barley is not as consistent as rice and pulses and appears in much smaller numbers (17% in level 15 to 5% in level 14). Wheat is only present in level 13 and is only one fragment. Small millets are present from level 16 to level 6 with exception of level 7. This plant type ranges from 43% (level 10) to 4% (levels 8 & 13). Parenchyma is present in small quantities in levels 11 and 14. Fruits only occur in three levels (13, 8, & 6) and only in small amounts. Weeds occur more frequently than fruits being present in eight levels. They are present from level 13 to level 5 with exception of level 10.

At Koldihwa, the two sections show quite different sequences of plant types even though they should represent the same levels on the site. In both sections the lowest samples taken from level 5 did not contain any plant material apart from some charcoal mostly found in Z1. No artefacts were found in these levels either. See figure 7.9 and 7.10 for relative frequency charts of both sections sampled. Section Z1 begins with a wide variety of plant types. Pulses, rice, small millets, indeterminate Gramineae, and weeds are all present in level 4. These pulses include *Vigna* sp. and lentils, therefore both summer and winter pulses are represented. Rice is present in all of the levels above level 4 and has its largest occurrence in level 2 (50%). All of the other plant types continue to be present throughout the samples with the addition of wheat and fruits in level 2. Wheat is not present in any other level.

Section Y1 starts with barley, which is only present as one fragment. Level 3 does not contain barley but has pulses, small millets, wheat, rice, and fruits present. This is the only level in section Y1 that contains rice and wheat. Levels 1 and 2 have the same plant types present but in different amounts; pulses, small millets, barley, indeterminate Gramineae, fruits, and weeds. In level 2, pulses and small millets have the largest amounts.

Weeds occur in the largest quantity in level 1. However, if the samples are combined further by putting the two sections data together then all of the plant types would be present in all levels with the exception of barley in level 3.

Absolute counts and vertical changes in plant taxa

The calculation of absolute counts has only been conducted for pulses and cereal grains that are identified to at least genus level. Figures 7.11 to 7.13 show vertical charts of absolute counts for Mahagara and Koldihwa. This demonstrates again the scarcity of remains found at these sites. At Mahagara, rice appears in small quantity in sample 52, along with indeterminate Gramineae (not on figure 11). It is clear with the absolute numbers as it was with relative frequencies that sample 50 has a significant increase in the quantity of plant material and the plant taxa present. *Vigna* sp., lentils, and pulse fragments are present along with small millets and barley. Although, it is not until sample 46 that a consistent presence of all the plant taxa can be seen. Sample 40 has the largest amounts of small millets and barley where as sample 39 has the largest amount of rice. From samples 29 upwards there is no presence of the major plant taxa except for some occasional small millets. Therefore the major organic input in to the site is between samples 46 and 30. Sample 40 has the largest amount of plant material.

At Koldihwa, section Y1 begins with barley in sample 17. There are no plant remains earlier than this. In sample 16, rice, wheat, and pulse fragments are present but barley is not present again until sample 14. All of the remains are in very small numbers, smaller than found at Mahagara. Generally, the amount of plant material increases moving up the sequence and this can especially be seen in small millets, barley, and weeds. Rice is only present in samples 15 and 16 and only in very small numbers. Sample 11 has the largest amount of plant material in section Y1, which is the latest sample.

In section Z1, the amount of plant material is again very small. The first sample to have plant material is sample 8, which contains *Vigna* sp., lentil, pulse fragments, rice and a weed seed. Barley is not present until the very top of the section in sample 1 and 2. There is more rice present in this section and one sample contains five grains. One wheat grain is present in sample 4. Sample 3 contains the largest amount of plant material in section Z1.

Comparing plant taxa - ratios

Comparing the data from different plant taxa may give some insight into how these plants became incorporated in the samples and whether different plant taxa relate to one another or not. This has been done for the different plant taxa found at Koldihwa and Mahagara. Tables of the ratios generated by this analysis can be seen in figures 7.14 and 7.15. All of the ratios showed little relationship between any of the plant taxa. This is probably the result of the poor preservation at these sites and also the small sample size used, which does not allow a true comparison of what would have been left in antiquity but just those fragments that have survived.

7.1.3 Results from Orissa

Density of plant material

As can be seen in the sample from the Belan River Valley, there are differences in the density of plant material between the sites sampled in Orissa. The density of the flotation samples per litre of sediment varies throughout the samples. This data can be found in the raw data tables in appendices 7.6 to 7.10. The largest flotation sample being MKA 2 (7.6 ml) and the smallest being 0.05ml in samples GPR 9 & 10. This does not necessarily mean that more charred material is in the larger flotation samples because other material can be found in the samples such as soil or modern plant roots. Two sites contain significantly more charred material than the other three; these are Gopalpur and Golbai Sasan. The other three sites (Bajpur, Malakhoja, and Banabasa) had little or no charred plant material. Again, at the later sites it may be a result of preservation and the phytolith analysis may reveal more information about why there is a scarcity of charred remains.

Presence/absence and ubiquity values of plant taxa

At Bajpur, there are very little charred remains and even charcoal is scarce. Samples 2 and 3 contained one indeterminate fragment each and sample 4 contained an indeterminate small millet. All of these were very badly preserved. The samples from Banabasa contain even less charred material. There are no fragments of seeds and only rare pieces of charcoal. Malakhoja also has a lack of charred plant remains. In sample 1 there are 3 rice grains although because of the scarcity of other charred remains this may well be intrusive. This lack of charred material means that any further analysis of macro-botanical remains cannot be done on these sites.

The samples from Gopalpur and Golbai Sasan are very different to those from the other three sampled sites. There is a large amount of different plant taxa found at these coastal sites, which represent all of the major plant types: pulses, small millets, large cereals, fruits, and weeds. The pulses present at Gopalpur are *Macrotyloma uniflorum* and *Cajanus cajan*. These pulses are also present at Golbai Sasan as well as *Vigna* sp. and *Vigna radiata*. These sites contain rather a lot of rice compared to the Belan Valley sites particularly Golbai Sasan. There is also a small amount of rice chaff at both sites. The coastal Orissan sites do not contain any winter pulses or winter cereals. There is a variety of small millets present: *Setaria* sp., *Panicum* sp., *Paspalum* sp., and *Echinochloa* sp. All of these are present at Gopalpur but Golbai Sasan just has *Setaria* sp. and *Paspalum* sp. Fragments of fruit stones are present at both sites. *Celtis* sp. is found at Gopalpur and

Ziziphus sp. at Golbai Sasan. There is also a variety of weeds present at both sites including sedges and wild grasses.

A comparison of ubiquity values for the different plant types found at Gopalpur and Golbai Sasan can be found in figures 7.16. This shows that the occurrence of the major plant types is similar for both sites. At Golbai Sasan, pulses and fruits occur more frequently than at Gopalpur. Rice, small millets, and weeds have very similar ubiquity values.

Relative frequency of plant types

Figures 7.17 and 7.18 show charts of the relative frequencies of the different plant types in the assemblages from Gopalpur and Golbai Sasan. At Gopalpur, pulses dominate the bottom of the section (samples 1-3). The largest amount of charred material is found in samples 2 and 3, which are near the bottom of the section. Large numbers of pulses (*Macrotyloma uniflorum* and pulse fragments presumably also horsegram) are found in samples 2 and 3 (168 and 248 fragments). Rice is present in all the samples and dominates the samples at the top of the section (samples 10-13). Although, the largest amounts of rice occurs in samples 6, 7, and 8. Weeds are present throughout the section with exception of sample 9. Small millets occur sporadically throughout and appear in larger numbers in samples 6 and 8 than are found in other samples. Single stones of *Celtis* sp. are found in samples 2 and 12.

At Golbai Sasan, a wide variety of plant types are present from the bottom of the section: pulses, rice, indeterminate Gramineae, fruits, and weeds. Rice dominates the bottom three samples and is a significant part of all samples in the section. The largest amount of rice is found in sample 9 (107 fragments). Pulses are also present in significant numbers in all samples. The largest number of pulses appears in the upper most sample (3 with 204 fragments) and this is the result of a large number of *Vigna* sp. seeds being present. Small millets occur infrequently throughout and are present in samples 14A, 13A to 9, 7A, and just one fragment in sample 3. They are only present in small amounts ranging from one to six fragments. Weeds are present in sample 14B to 8 with the exception of sample 13A. They are also only present in small amounts ranging from one to five fragments. Fruits are present sporadically throughout the section and appear in their largest numbers in samples 9 and 14B (70 and 16 fragments).

Absolute counts and vertical changes in plant taxa

The calculation of absolute counts still shows that a significantly larger number of charred remains have been found at the coastal Orissan sites to those found at the Belan Valley sites. Vertical bar charts of Gopalpur and Golbai Sasan can be seen in figures 7.19 and 7.20.

At Gopalpur, pulses particularly *Macrotyloma uniflorum* dominate the lower part of the section. Sample 2 and 3 have the largest amounts of this pulse species (27 and 32 seeds). *Cajanus cajan* is only present in sample 2 at this site and 1 whole seed was found. Pulses fade away moving up the section and rice increases in importance. Although, rice is consistently present throughout the section but not in large quantities. The absolute counts for rice range from one to ten grains. The largest amounts occur in samples 6 and 8. These samples also have the largest number of small millets in the section. From sample 8 upwards charred material decreases until sample 15 where there is no plant material present.

At Golbai Sasan, rice dominates the bottom of the sequence but there are a number of different plant taxa also present; weeds, pulse fragments, small millets, and fruit fragments. It is not until sample 12 that there is significant input from all of the plant taxa.

Sample 9 has the largest amount of charred material including the largest amounts of rice, weeds, and fruit fragments. Sample 3, the uppermost sample, has the largest amount of pulses, particularly *Vigna* sp. This taxon is also present in small numbers, ranging from one to four, in samples 13D, 13C, 12, 11 and 9 but occurs in much larger number in sample 3 (36.5). *Cajanus cajan* is present in three samples (10, 9, and 3) and only in small amounts. *Macrotyloma uniflorum* is present sporadically throughout the section and is also only present in small amounts.

Comparing plant types - ratios

The greater amount of charred material found at the coastal Orissan sites means that comparison between the different plant types is likely to be less influenced by preservation issues and changes in the data reflect ancient patterns and possibly activities. Figure 7.21 shows a table of comparison values of Gopalpur plant types and figure 7.22 shows ratios from Golbai Sasan. These two sites have similar patterns, when comparing plant types. Rice and weeds correlate well as does rice and small millets with weeds. Rice and pulses do not correlate well at either site but at Golbai Sasan there is some correlation if an outlier (sample 3) is removed from the comparison. Pulses do not correlate with either small millets or weeds. This may suggest that these two crops are treated differently in terms of crop processing. Rice and small millets correlate well at Gopalpur (0.79) but not as well at Golbai Sasan (0.35), which may suggest at the former site they are primarily rice weeds and at the later may be a separate crop plant. Therefore at Golbai Sasan, *Setaria* sp. or *Paspalum* sp. may have been cultivated as crops although they only appear in very small numbers in the macro-botanical assemblage and there are more small millets that were not identified to genus or species level so another small millet is also just as likely.

7.2 Phytolith analysis results

7.2.1 Identification of phytolith remains

A lot of discussion has focused in this thesis on the identification of rice (particularly chapter six). Different rice phytolith parts have been counted in this project even though it is recognised that there are certain problems with some of them. For the single celled phytoliths, rice bilobes, rice bulliforms, and rice double-peaked glume (or husk, whatever name is used they are the same thing!) cells are recorded. These are only recognised as these particular parts if they are classic examples of these types (examples of these can be seen in appendix 5.4). Any variation and they were counted in the general categories for these morphotypes: keystone or bilobes (double-peaked 'glume' cells does not have a general category because they are easily distinguished). As far as rice husk is concerned, these were only recognised if the particular cell pattern and peaked cells were present. If only the cell pattern was present then these multi-cells were recorded as cereal husk. Rice leaf/stem was recorded when more than one scooped rice bilobe was present in a horizontal position. Other multi-celled categories are explained in appendix 5.4 including photographs of some examples.

The majority of categories used for counting are general and not specific to a particular genus or species. However, within some of these categories there was great variation especially keystones and bilobes. Bambusoid type keystones were seen and also some that may have been other grasses such as *Cynodon* sp. but there was a great deal of variation in most of the samples, which demonstrated the presence of various leaf material.

Another category, which needs to be discussed, is rugulose spheroid. The majority of scholars would recognise this category as date palm, however in this region there are many different palms. An examination of the leaves of the three most common palms has taken place: date palm, palmyra palm, and coconut palm. They are all fairly similar to each other although palmyra palm has some larger rugulose spheres as well as the small ones. Some of the rugulose spheres in this project, were the ones consistent with date palm, having regular small spines and being fairly small in size although these have also been seen in other palms so these are not diagnostic to a genus or species. There were also some larger spheres with regular spines but there were some that had irregular spines too, some much longer than others. Reference material matching the last spheres has not yet been found. More work needs to be conducted on palm species because even though these phytoliths could come from the common palms, which are economic plants, they may also be from the many other species that exist in these tropical areas. Therefore for the moment they have all been put in this general category.

There was one consistently recurring multi-cell (found only at Golbai Sasan), which was unidentifiable (indet multi-cell type one). This was a panel of papillae type cells all grouped together sometimes in a random configuration and sometimes in uniform rows. This may be part of the tip of a grass husk, which looks fairly similar but not as compact. I have not seen anything that is exactly like these panels so no identification can be put forward at present.

7.2.2 Results from Uttar Pradesh

In this project, phytolith samples from Koldihwa and Chopani Mando have been analysed. Phytolith analysis on samples from Mahagara has been previously conducted by the author (Harvey 2002) and this information will be presented here again so that it can be compared to the other Belan River Valley sites easily. More detailed analysis will also be conducted of this data and the ability to compare it especially with the data from Koldihwa will add a great deal to the interpretation of the site. It was also not possible to previously assess the data along with the macro-botanical results, which may again change the interpretations previously suggested.

Presence/absence of morphotypes

Results tables for all of the Belan River Valley sites can be found in appendices 7.11 to 7.13. At Chopani-Mando, there is quite a large variety of single-celled morphotypes present in the samples both monocotyledons and dicotyledons but very few multi-celled phytoliths were present in any of the samples. Long smooth, bulliforms, and keystones are the most common morphotypes in the samples. Rugulose spheres (Palmae) are present in all of the samples and these include some with irregular spines. Throughout the whole section there are no cereal remains present at all. Therefore no rice was present or any millet remains. A few indeterminate leaf/stem fragments are present in samples 3, 5, and 7. Unidentifiable husk is present in sample 1 as well as a Cyperaceae multi-cell.

At Koldihwa and Mahagara, there is a larger variety of morphotypes present than is seen in the samples from Chopani Mando. The most apparent difference is the common appearance of multi-celled phytoliths in general but these include cereals such as rice and millets. There were no multi-celled phytoliths at Mahagara or Koldihwa that could be identified as wheat or barley, which may have been expected from their occurrence in the macro-botanical assemblages. However, rice is clearly a large part of the samples from Mahagara and Koldihwa and is present as both multi-celled and single-celled phytoliths. Long smooth, bulliforms, and keystones frequently occur as at Chopani Mando but there are also morphotypes such as long dendritic, crosses, flat tower, tracheids, and sheets that occur much more frequently at Koldihwa and Mahagara. Dicotyledon single celled phytoliths are more common especially at Koldihwa.

Relative frequencies

Tables of the relative frequencies can be seen in appendices 7.14 to 7.16 and graphs of the relative frequencies can be found in figures 7.23 to 7.28. At Chopani Mando, long smooth morphotypes have the highest relative frequency ranging from 48% to 55% of the total single-celled assemblage. Bulliforms and keystones are the next frequent in the samples. Keystones have their highest frequency in sample 1 being 20%. Bulliforms range from 9% to 19% with the largest amount occurring in sample 5. After these morphotypes, rugulose spheroids are the next highest occurrence in the assemblage ranging from 2% to 4%. The most frequently occurring multi-celled type is in fact not a phytolith but is diatoms, which makes up 100% of the total multi-celled assemblage in sample 9. Silica aggregates are also common when they are present in samples ranging from 33% to 56%. Indeterminate leaf/stem occurs in samples 3, 5, and 7, and ranges from 6% to 33%. Unidentifiable husk only occurs in sample 1 and makes up 14% of the total multi-celled component of that sample.

The relative frequencies for Koldihwa show that there is a more even spread of occurrence over more morphotypes than are found at Chopani Mando. Long smooth, bulliforms, and keystones make up a large part of most of the single-celled assemblage but bilobes also have a similar occurrence. Long smooth range from 11% to 24 %, the highest occurrences occurring in samples 7 and 11. Bilobes make up more of the assemblage in the top of the two sections than the lower parts. The highest percentage occurs in sample 1 (29%) with the lowest occurrences for the two sections are in sample 6 (Z1/5) of 6% and in sample 11 (Y1/5) of 3%. Keystones have the opposite pattern as they are low at the top of the sections and the frequencies in the assemblage gets higher going down. In section Z1, sample 1 has 4% but by sample 6 (Z1/5) keystones make up 26%. Bulliforms occur in varying amounts throughout both sections. The largest percentages occur in samples 5 and

9 both being 18%. The next largest occurring morphotypes are long dendritics, rondels, and saddles. The highest occurrence of long dendritics occurs in sample 3 (10%). Rondels range from 2% to 10% and saddles range from 3% to 11%. Rice single-celled types occur in small numbers. Double peaked glume cells have the largest occurrences of these types of phytoliths ranging from 0.3% to 1.8% of the assemblage. Dicotyledon single-celled morphotypes occur in small numbers throughout the samples. Sheet and elongate types occur in the largest percentages ranging from 0.7% to 4% and 0.2% and 3%.

The multi-celled phytolith assemblages are dominated by four morphotypes types: indeterminate leaf/stem, unidentified husk, cereal husk, and rice husk. Generally, all of these types are present in higher percentages at the top of the sections and the amounts decrease going down the sections. The highest percentage for indeterminate leaf/stem occurs in sample 7 (40%) and for unidentifiable husk in samples 2 and 4 (both 36%). Cereal husk occurs in greater percentages in section Z1 to Y1 and the largest frequency is 28% in sample 3. Rice husk occur most frequently in sample 8 (35%) and ranges from 6% to 28% in section Z1 and from 7% to 35% in section Y1. Rice leaf/stem occurs in small amounts in some samples ranging from 0.8% to 1.9%. Cyperaceae has the opposite pattern to the types above. It occurs most in the lower samples and therefore may not have been brought to the site as a weed of the crop plants. Its largest frequency is in sample 10 (72%). Millet husk only makes up a small part of the multi-celled assemblages. Sample 1 has the largest frequency being 4%. *Phragmites* stem, square cell leaf/stem, polyhedral hair base, and silica aggregates only occur in very few samples and in small percentages.

The relative frequency of samples from Mahagara is similar to that of Koldihwa. Again long smooth, keystones, and bilobes are some of the highest occurring morphotypes in each single-celled assemblage but at Mahagara long dendritics and saddles also occur in similar amounts. Long smooth phytoliths range from 7% to 35% and the largest three percentages occur in samples 8 to 10 at the top of the section. Keystones increase in frequency going up the section and the largest percentage occurs in sample 9 (30%). The frequency of bilobes in the samples generally decreases up the section with the lowest sample being sample 9 (2%) and the largest sample is sample 3 (25%). The amount of saddles varies throughout the section ranging from 3% in sample 10 to 30% in sample 1. After sample 1, where the amount of long dendritics is 4%, the amount rises sharply and then decreases. Sample 2 has 20% and sample 10 has 5%. The lowest amount is in sample 8 being 3%. Bulliforms, long sinuate, and crosses are the next frequent types of single-celled phytoliths. Bulliforms vary in frequency throughout the section ranging from 0.8% to 9%. Long sinuate types are fairly consistent with most samples having between 4% and 5%. Sample 2 has the largest percentage of 10% and sample 9 the lowest being 2%. Crosses vary between 1.2% and 7%. Crenates and rondels occur in all of the samples but in small frequencies. All of the rice single-celled types again occur in small number but not in all of the samples. There are no rice single-celled phytolith in the top three samples (8 to 10). Dicotyledon single-celled phytoliths occur in smaller frequencies than at Koldihwa but different types are more common. Rugulose and smooth spheroids occur more frequently and in higher percentages at Mahagara. Elongates, tracheids, and sheet types occur in most of the samples but are in lower percentages than occur at Koldihwa.

In the multi-celled assemblages, indeterminate leaf/stem and unidentifiable husks make up a significant part of most samples except for sample 8 to 10. Unidentifiable husk occur more frequently than indeterminate leaf/stem. It occurs most frequently in samples 3 and 6 (both 62%). Rice husk occurs in samples 1 to 7 and ranges from 2.9% to 12.8%. It occurs much less frequently than at Koldihwa. Rice leaf/stem are not present in any of the samples. Diatoms make up a large percentage of some samples especially samples 1, 2, and 8 to 10. Sample 10 has the largest percentage being 94.4%. Millet husk occurs sporadically throughout the sequence in low percentages (1.3 to 5.8%). Cyperaceae occur in half of the samples in low amounts and *Phragmites* stem only occurs in three samples (samples 3 to 5).

Absolute densities

The calculation of the density makes it possible to compare between samples in a different way to using relative frequencies. In this case, the density is calculated of the number of phytoliths per gram of sediment type. Graphs of the different totals of phytoliths per gram of sediment can be found in figures 7.29 to 7.34. The total amount of phytoliths per gram of sediment found in the samples from Chopani Mando is a substantial amount (see figure 7.29). The highest number is in sample 3 being 19,201. The lowest number is in sample 9 being 1711. The majority of the samples are made up of predominantly single-celled phytoliths. Multi-celled phytoliths only occur in very small amounts ranging from 2 (sample 7) to 19 (sample 3) per gram of sediment (see figure 7.30). This is an extremely low amount.

The calculation of the absolute densities does create a slightly different pattern for the individual morphotypes than the relative frequencies at Chopani Mando (see figures 7.35 and 7.36). This highlights differences in the amount of long smooth, bulliforms, and keystones morphotypes between the samples. Sample 3 has a much higher density of long smooth cells (10,057), bulliforms (2730), and keystones (2863) than other samples except for sample 1, which also has similar amounts of bulliforms and keystones. With the absolute densities, sample 3 has the largest amount of bilobes (133) and rondels (333) but with relative frequencies bilobes is highest in sample 9. All other patterns are similar to that found using relative frequencies. Densities of multi-celled phytoliths also show a similar pattern apart from sample 3 having a higher density of diatoms than sample 9.

Koldihwa has a much higher total density of phytoliths. Sample 2 has the largest total amount being 700,918 per gram of sediment (see figure 7.31) and also the largest amount of single-celled phytoliths, which is 552,152. Generally for both sections the top two layers have higher densities of phytoliths than the lower samples in the section. This means that the Chalcolithic and Iron Age layers are higher in phytoliths than the Neolithic levels, which is also generally true of the macro-botanical remain densities. There are much larger densities of multi-celled phytoliths at Koldihwa than at Chopani Mando. Sample 2 again has the largest amount being 148,766 per gram of sediment. The multi-celled phytoliths follow the same pattern as the single-celled phytoliths with larger densities at the top of the sections. The lowest number of multi-celled phytoliths per gram of sediment is found in sample 11 (749).

Again, the calculation of absolute densities draws out a different pattern than found with relative densities for individual morphotypes at Koldihwa (see figures 7.37 and 7.38). There seems to be more differences between the samples using this method of analysis. Sample 2 has the largest densities for bilobes (141,614), long smooth (120,157), long dendritics (55,787), rondels (57,217), tracheids (15,734), and for sheets (14,304) The same general pattern still occurs for bilobes as was found with relative frequencies except that the densest sample for section Z1 occurs in sample 2 rather than sample 1. Bulliforms and keystones also have some of the largest densities being 47,780 in sample 1 and 42,465 in sample 6. The single-celled rice phytoliths again occur in small amounts compared to other morphotypes. Double-peaked glume cells range from 124 to 6615 per gram of sediment and all of these types decrease in density going down the two sections. For the majority of multi-celled phytoliths there is a general pattern of decreasing density going down the two sections. In section Z1, sample 2 again has the highest density for most of the morphotypes. Section Y1, has its highest densities for multi-celled phytolith types most commonly in sample 7 but for rice husk and Cyperaceae it is in sample 8. Rice leaf/stem is only present in small numbers and occurs more in section Y1.

At Mahagara, there is a lower density of total phytoliths than is found at Koldihwa and even lower than at Chopani Mando. The largest sample at Mahagara is 17,427 per gram of sediment in sample 5 (see figure 7.33). However, the number of multi-celled phytoliths is much larger than at Chopani Mando (see figure 7.34). The largest density of multi-celled phytoliths is found in sample 3 (2206). Sample 3 to 7 have much larger densities of all phytolith than the other samples in the section.

For the individual morphotypes there is also a very different pattern apparent using absolute densities at Mahagara (see figure 7.39 and 7.40). Long smooth cells are much less important in samples than is suggested by relative frequencies. Keystones have the largest density of phytolith overall and have the highest morphotype density in samples 5 (3635), 6 (3185), 4 (1988) and 7 (1973). Bilobes, saddles, and long dendritics also have large densities in most samples. Bilobes range from 3069 in sample 5 to 40 in sample 9. Saddles occur in the highest density in sample 5 (2342). Samples 3 to 5 have the highest density of long dendritic cells. Bulliforms are much more dense in sample 5 (969) and 7 (839) compared to other samples. The rice bulliform and bilobe phytoliths both have their largest densities in sample 7, which is the same as found with relative frequencies. The double-peaked glume cells, however, are densest in sample 6 rather than sample 1 with relative frequencies. The dicotyledon single-celled phytoliths show a similar pattern to that found with relative frequencies. The multi-celled phytoliths also demonstrate a different pattern using absolute densities. Unidentifiable husks have the largest densities in the majority of samples. Sample 3 has the largest density of this morphotype (1376). This sample also has the largest density of rice husks (283) and long smooth cells (434). Sample 3 through to 7 generally have more multi-celled phytoliths than other samples. The very top of the sequence has very low densities of multi-celled phytoliths except for diatoms. But, diatoms appear much less important by using absolute densities.

Grass subfamilies

For graphs showing the differences in the grass subfamilies see figures 7.41 to 7.43.

At Chopani Mando, there is no clearly dominant grass subfamily. Chloridoid has the largest densities in sample 1, 5, and 9 but these are fairly low except for sample 1. Festucoid grasses show the largest density out of all the samples in sample 3. Panicoid grasses are also fairly dense in this sample. These grasses have the largest density in sample 7 but festucoid grasses also have a similar density.

At Koldihwa, panicoid grasses dominate the majority of samples. They have very large densities in samples 1 and 2 compared to the other subfamilies and also compared to the rest of the samples. These are the top two samples from section Z1. Panicoid grasses also have the highest densities in samples 7 and 8, the top two samples of section Y1, but there is not such a large difference between them and the other grass sub-families as is found in samples 1 and 2. Samples 9 to 11 have the lowest densities of all of the subfamilies and contain less of all the grasses than other samples.

At Mahagara, panicoid and festucoid grasses have a similar pattern in all samples but panicoid grasses clearly dominate samples 3 to 7. Their highest density is in sample 5. Chloridoid grasses have the largest density in samples 1, 2, 8, and 9. Festucoid grasses are only present in small numbers throughout the samples compared to the other sub-families. There is the greatest difference in this subfamily to the others in samples 2 to 7.

Comparing single-celled phytoliths using ratios

At Chopani Mando, the single-celled phytoliths with large densities (long smooth, long dendritic, bulliforms, and keystones) have been compared to try to establish whether they have any relationship. This will help to determine the source of this material. Table of these comparisons can be seen in figure 7.44. This analysis shows that there is a correlation, generally a very good one, between these morphotypes.

At Koldihwa, for single-celled phytoliths this analysis was carried out on a larger variety of morphotypes (long smooth, long dendritic, bulliforms, keystone, bilobes, crosses, saddles, and rondels) because these samples were generally more variable in terms of morphotypes than those from Chopani Mando. Figure 7.45 shows a table of these comparisons. The majority of these morphotypes correlate well especially long smooth with long dendritic, and bilobes with crosses and also with rondels. Bulliforms do not correlate well with keystones or other morphotypes. Saddles also do not seem to correlate well with other morphotypes particularly with rondels. The only morphotype that saddles correlate fairly well with is bulliforms.

The same comparisons were carried out for the samples from Mahagara with a fairly similar outcome (see figure 7.46). Again long smooth correlates well with long dendritics as well as most of the other morphotypes. Long dendritics correlate well with bilobes and crosses but not as well with rondels and saddles although there is still some relationship. Bulliforms do not correlate with any other morphotype including keystones. At Mahagara, saddles correlate well with the other morphotypes but crosses and rondels do not correlate well together.

Comparing plant parts using ratios

Comparative analysis of multi-celled plant cells and the single-celled rice phytoliths has been conducted for Koldihwa and Mahagara. There are not enough multi-celled phytoliths nor any rice phytoliths present at Chopani Mando to carry out this analysis. At Koldihwa, there are rather mixed results (see figure 7.47). Rice husks correlate well with rice bilobes, indeterminate leaf/stem, unidentifiable husk, millet husk, and cereal husk but only have some correlation to double-peaked glume cells. They do not correlate with rice bulliforms or rice leaf/stem. Rice leaf/stem does not correlate with any of these morphotypes. The single-celled rice phytoliths generally do not correlate well together. There is some correlation between rice double peaked glume cells and rice bilobes. Rice bulliforms also has some correlation with the glume cells but correlates very well if sample 3 is excluded. Rice bilobes and rice bulliforms do not correlate.

At Mahagara there is generally more correlation between the multi-cells and also between the rice single-celled phytoliths than is found at Koldihwa (see figure 7.48). Rice husks correlate well with all of the rice single-celled phytoliths, if samples 2 and 3 are excluded. They also correlate well with indeterminate leaf/stem, and unidentifiable husks. The single-celled rice phytoliths do not correlate with these multi-celled phytoliths. There are no correlations with millet husk. Rice bulliforms and rice bilobes correlate well and the other single-celled phytoliths have some correlation to each other. This suggests a contrast between Mahagara and Koldihwa.

7.2.3 Results from Orissa

Phytolith samples have been analysed from four sites in Orissa: Gopalpur, Golbai Sasan, Bajpur, and Malakhoja. Phytolith samples from Banabasa were unavailable for analysis.

Presence/absence of morphotypes

Results tables for the four Orissan sites can be seen in appendices 7.17 to 7.20. Malakhoja and Bajpur show a similar pattern of presence/absence of phytoliths to those found at Chopani Mando. Both of these Orissan sites contain a large variety of monocotyledon and dicotyledon single-celled phytoliths but have very few multi-celled phytoliths. Malakhoja has some indeterminate leaf/stem, unidentifiable husk, Cyperaceae, and silica aggregates. This site is dominated by long smooth, bulliforms, and keystones. Blocks and sheets are the most common of the dicotyledon single-celled phytoliths although they appear generally a lot less than the monocotyledon phytoliths.

Bajpur also has small amounts of the same multi-celled phytoliths that are found at Malakhoja as well as a small amount of rice husks present that may be intrusive. There are also small amounts of rice bulliforms and rice bilobes in some of the samples. Again, long smooth, bulliforms, and keystones are the most common single-celled phytoliths. Bilobes and saddles are also more common than other morphotypes but in much smaller amounts than the previously mentioned types. Elongate and sheet are the most common dicotyledon phytoliths and again these only appear in small numbers compared to the monocotyledons.

Gopalpur and Golbai Sasan have a very different presence of phytoliths to Bajpur and Malakhoja. Both sites have a wider variety of single-celled phytoliths and most significantly a much larger amount of multi-celled phytoliths. This is a similar pattern to what has been found in the phytolith assemblages from Mahagara and Koldihwa. At Gopalpur, long smooth, long dendritic, bulliforms, keystones, bilobes, crosses, rondels, and saddles are all frequently present in the samples. Dicotyledon phytoliths seem to appear more frequently especially sheets. All of the single-celled rice phytoliths are present in small numbers. As well as there being more multi-celled phytoliths, there is also more variety with cereal husk, rice husk, rice leaf/stem, and millet husk being present in varying amounts.

At Golbai Sasan, long smooth, long dendritic, bulliforms, keystones, bilobes, rondels, and saddles are the most commonly occurring single-celled phytoliths. Rice single-celled phytoliths are more common at this site especially rice bilobes and double-peaked glume cells. Tracheids and sheets are the most common dicotyledon phytoliths. Multi-celled phytoliths are dominated by rice husks but indeterminate leaf/stem, unidentifiable husk, cereal husk, Cyperaceae, and silica aggregates are also common. The indeterminate multi-celled phytolith type 1 occurs at both Golbai Sasan and Gopalpur.

Relative frequencies

Tables of relative frequencies for all of the Orissan sites can be found in appendices 7.21-7.24 and graphs of relative frequencies can be seen in figures 7.49 to 7.56. At Bajpur, there are three morphotypes that dominate the samples: long smooth, bulliforms, and keystones. Keystones have the highest relative frequency being 46% in sample 3 and the lowest is in sample 0 (36%). Long smooth has the next highest frequency in the samples. These morphotypes range from 33% in sample 1 to 19% in sample 0. The other morphotypes present occur much less frequently. Saddles, trichomes, and long sinuate are the next most frequent morphotypes. Rice bulliforms occur in samples 0 to 2 in small frequencies the highest in sample 0 (1.4%). Rice bilobes are also present in sample 0 (0.2%). Dicotyledon single-celled phytoliths are all present in very low percentages. Silica aggregates dominate the multi-celled phytolith assemblages in all samples and make up 100% of samples 1 and

4. Indeterminate leaf/stem is present in sample 0 and 2 (11% and 13%). Unidentifiable husk, Cyperaceae, and rice husk are only present in sample 0 in very small frequencies.

Long smooth, bulliforms, and keystones are again the morphotypes with the highest frequencies in the samples from Malakhoja. Keystones have the highest frequency of 44% in sample 4 and the lowest frequency for this type is in sample 9 (36%). Long smooth types range from 33% (sample 1) to 23% (sample 4). Bulliforms range from 16% (sample 1) to 11% (sample 4). All of the other morphotypes have much lower frequencies. Long sinuate, trichomes, saddles, and rondels are the next frequent morphotypes. Blocks are also similarly occurring ranging from 5% in sample 4 to 0.8% in sample 1. No single-celled rice phytoliths have been found. Again, silica aggregates are the most frequently occurring multi-celled phytolith. Indeterminate leaf/stem occurs in sample 1 (25%) and 4 (4%). Unidentifiable husk and Cyperaceae occur in small frequencies in sample 9. There are no other multi-celled phytoliths including rice phytoliths.

At Gopalpur, keystones and long smooth have the highest frequencies in the majority of samples. Keystones have high frequencies in sample 6, 12, and 14 (38%, 39%, and 39%). The lowest value occurs in sample 2 (7%). Long smooth type has highest frequencies in sample 2, 4, and 10 (34%, 35%, and 33%). In the rest of the samples, this morphotype makes up between 20% and 30% of the assemblage except for in sample 13 (11%). After these types, bulliforms and bilobes are the most frequent in the samples. Sample 8 has the highest frequency of bulliforms (21%) and sample 11 and 13 have the highest frequencies of bilobes (19% and 23%). The other samples have between 11% and 20% frequencies for bulliforms except for sample 2, which has only 8%. Most of the other samples have much lower frequencies of bilobes, the lowest being in sample 10 at 0.9%. Long dendritic ranges from 9% to 0%. Rondels and saddles are the next frequent morphotypes. Rondels range from 12% in sample 13 to 1% in sample 4. The highest frequency of saddles is 7% in sample 8. All of the rice single-celled phytoliths occur in low frequencies. Rice bilobes are the least frequent and only occur in 6 of the samples. Double-peaked glume cells are the most frequent occurring in 11 of the samples (not in samples 4, 10, and 14) and range from 2.2% (sample 1) to 0.3% (sample 5). Dicotyledon single-celled phytoliths generally occur in low frequencies in the assemblages but in sample 2 to 4 sheet types occur much higher than other types (13%, 18%, and 17%).

Multi-celled phytoliths are fairly varied throughout the samples. Silica aggregates have the highest frequencies but only in four samples (3, 4, 5, and 10) and frequencies range from 100% to 0%. Rice husks are present in nine samples and have the highest frequencies in samples 2, 6, 8, 9, 11, and 14 (55% to 39%). Indeterminate leaf/stem and unidentifiable husk occur in varying amounts throughout the samples. Indeterminate leaf/stem occurs most frequently in sample 6 (29%) and unidentifiable husk is highest in samples 1, 7, and 13 (38%, 44%, and 34%). Rice leaf/stem occur in low frequencies; the highest being in sample 13 (3%). Cereal husk, millet husk, and square cell leaf/stem occur in low frequencies. Cyperaceae varies a lot throughout the samples. Sample 1 and 9 have the highest frequencies being 34% and 20%. Some samples do not have this morphotype at all (samples 3, 4, 5, and 10).

At Golbai Sasan, keystones have the highest frequency of all the morphotypes being 39% in sample 7B. The lowest frequency is in sample 3 (17%). Long smooth and bulliforms also have high frequencies. Long smooth is fairly consistent throughout the samples and ranges from 28% in sample 14A to 18% in sample 7A. Bulliforms have more variation ranging from 29% in sample 1 to 9% in samples 9 and 10. The next highest frequency morphotypes are long dendritics, bilobes, rondels, and saddles. They occur at much lower frequencies than the first three types. Long dendritics ranges from 7% in sample 1 to 1.2% in sample 8. Bilobes have the highest frequencies in samples 3, 9, 10, and

11 (12%, 14%, 10%, and 11%) and the rest of the samples are all under 6% frequency. Rondels and saddles have similar variations in the samples; rondels range from 8% (sample 9) to 0.6% (sample 1) and saddles range from 8% (sample 14B) to 0.7% (sample 13A). There are higher frequencies of rice single-celled phytoliths at Golbai Sasan than are found at Gopalpur. These morphotypes occur in more samples and double-peaked glume cells have the highest frequencies of 3% in samples 10 and 12. Dicotyledon single-celled phytoliths seem to occur in similar low frequencies to those found at Gopalpur. Sheet and tracheids have the highest frequencies being 3% in samples 10 and 14B and 2% in sample 11 respectively.

The multi-celled phytoliths are dominated by rice husks and in the majority of samples they represent the type with the highest frequency. They occur in all of the samples. Three samples have over 60% frequency of rice husk; samples 7B, 13A, and 14C. The lowest frequency is in sample 1 (24%). Indeterminate leaf/stem and unidentifiable husk also make up a large part of most of the multi-cell assemblages. For both types, the highest frequencies occur in sample 1 and 3. Indeterminate leaf/stem ranges from 24% in sample 1 and 3 to 6% in sample 8. Unidentifiable husk ranges from 30% in sample 1 to 8% in sample 14C. Cereal husk occurs in all of the samples and ranges from 29% in sample 14B to 1% in sample 1. Millet husk only occurs in four samples and in low frequencies. Rice leaf/stem is more frequent at Golbai Sasan than at Gopalpur. Silica aggregates are much less frequent. Cyperaceae occurs most frequently in samples 4A and 7A (9% and 8%) but only has even lower frequencies in the other samples. Square cell leaf/stem is present in the majority of samples but only in low frequencies.

Absolute densities

The total densities of phytoliths from Bajpur are fairly consistent from samples 0 to 3 but there are a lot more phytoliths in sample 4 (see figure 7.57). Sample 4 has the highest density of phytoliths (168,157). All of the samples are dominated by single-celled phytoliths and multi-celled phytoliths are only present in very small densities (see figure 7.58). Sample 0 has the highest density of multi-celled phytoliths (128).

For the absolute densities of individual morphotypes from Bajpur, see figures 7.59 and 7.60. There are similar patterns with the absolute counts to those found with relative frequencies however sample 4 demonstrates much larger densities for keystones, bulliforms, and long smooth cells than the other samples. These morphotypes have 76,349, 25,256, and 42,384 phytoliths per gram of sediment. Sample 4 also has the highest densities for saddles, elongates, and sheets types. The pattern for multi-cells with absolute densities is again the same as with relative densities.

The total absolute density of phytoliths from Malakhoja is highest in sample 4 (79,373). See figures 7.61 and 7.62 for charts of the total absolute densities of phytoliths from Malakhoja. The lowest density of total phytoliths is in sample 9. Again the majority of the total densities are made up of single-celled phytoliths. Multi-celled phytoliths appear in very low densities throughout all of the samples, which is a similar pattern to Bajpur. The highest density was found in sample 4 (99) but sample 9 (89) was also much higher than samples 1 and 7.

For the absolute densities of individual morphotypes from Malakhoja see figures 7.63 and 7.64. The absolute densities show similar patterns to those found with relative frequencies although there is again more variation between the samples shown with absolute densities. Keystones have the largest densities especially for sample 4, which has a much larger density than the other samples. Sample 4 also has the largest density of bulliforms, long smooth, saddles, and block phytoliths. Bulliforms and long smooth have the next highest densities to keystones. Bulliforms range from 9326 in sample 4 to 1855 in sample 9. Long smooth types have higher densities than bulliforms ranging from 18,6532 in sample 4 to 4039 in sample 9. The other single-celled morphotypes show a similar pattern to that found with relative frequencies as do multi-celled phytoliths.

Charts of the total absolute densities of phytoliths from Gopalpur can be found in figure 7.65 and 7.66. The highest density of phytoliths is found in sample 13 (245,417). This is much larger than is found at Bajpur and Malakhoja. Sample 13 is much more dense that the other samples from Gopalpur. The next highest density is in sample 9 (66,622). Samples 11 and 6 also have fairly similar densities to sample 9 (59,372 and 49,871). Samples 1 to 5 are particularly low in density compared to the rest of the samples. This means that the bottom of the section has lower densities of phytoliths than the top. The lowest density is in sample 1 (1579). At Gopalpur, multi-celled phytoliths are in much higher densities than has been found at Bajpur and Malakhoja. The highest density of multi-celled phytoliths is found in sample 13 (21,522). Samples 11, 7, and 6 also have high densities of multi-celled phytolith compared to the other samples although they are much less than in sample 13 (5262, 4621, and 1965). The rest of the samples have much lower densities of multi-celled phytoliths and the lowest density is in sample 14 (51).

The absolute densities for individual morphotypes can be found in figures 7.67 and 7.68. These values demonstrate different patterns to those found with relative frequencies. Bilobes have the highest density overall, which is found in sample 13 (52,489). This is a much larger figure than is found in the other samples. The lowest density for bilobes is 20 in sample 4. Sample 13 has the highest densities for the majority of morphotypes and they are mostly much denser than the other samples. This is not the case for keystones where sample 13 and sample 6 have similar densities (19,045 and 18,380). Generally, samples 1 to 5 have much lower densities of all morphotypes than the other samples from Gopalpur. The densities of the rice single-celled phytoliths are quite low compared to some of the other morphotypes such as bulliforms, keystones, and long smooth. The largest densities of the rice morphotypes are found in sample 13. Dicotyledon single-celled phytoliths have a similar pattern to that found with relative densities. Tracheids, sheet, and elongates have the largest densities.

Multi-celled phytoliths from Gopalpur show quite a different pattern with absolute counts to those found with relative densities. Silica aggregates are much less significant than is suggested with relative counts. Sample 13 has the highest densities for indeterminate leaf/stem and unidentifiable husk, which are much higher than for other samples (8051 and 7432). This sample also has the highest densities for cereal husk and rice leaf/stem (1238 and 774) however these are much less dense than the previously mentioned morphotypes. Samples 13 and 11 have the highest densities for rice husks (3096 and 2923) and this morphotype is present in 10 of the samples. There are less rice husks and rice leaf/stem phytoliths present in samples 1 to 5 than there are in samples 6 to 14.

For charts of the total densities for phytoliths from Golbai Sasan, see figures 7.69 and 7.70. There is a similar range of densities found at Golbai Sasan to those found at Gopalpur. Samples 11 and 9 have the highest densities of phytoliths (269,153 and 235,603). Samples 1 to 8 generally have lower densities than samples 9 to 14C. This is the opposite pattern to that found at Gopalpur as at Golbai Sasan there are higher densities at the bottom of the sequence. The lowest density is found in sample 4B (12,437). There is a similar pattern with the multi-celled phytoliths. Samples 9 to 14C have larger densities than the samples from the top of the section with samples 11 and 9 again having the highest densities (61,695 and 43,375).

At Golbai Sasan, the absolute densities for individual morphotypes are shown in figures 7.71 and 7.72. The pattern for absolute densities again shows difference from those found with relative frequencies. There is more difference between the samples using absolute densities. Samples 11 and 9 show the highest densities for the majority of morphotypes. Long smooth has the highest density (50,847 and 45,560), which is followed by keystones, bulliforms, bilobes, rondels, and saddles. These morphotypes are much denser in these two samples especially long smooth, keystones, and bilobes. These samples also have the largest density of long dendritics although these are less dense than the former morphotypes. Sample 7A has more hairs than other samples (2563). Rice single-celled phytoliths appear in larger densities at Golbai Sasan than are found at Gopalpur. Samples 11 and 9 have the highest densities of rice bilobes (4067 and 3120) and double-peaked glume cells (3389 and 3120). The highest density of rice bulliforms is found in sample 12 (744). There are generally higher densities of dicotyledon single-celled phytoliths than was found at Gopalpur.

There is some similarity between the pattern of absolute densities for multi-celled phytoliths and that found with relative densities. Rice husks still have the highest values with the highest densities this time being in samples 11 and 9 (29,152 and 24,340). The densities are much higher in samples 11 and 9 than in the other samples and this is also found for indeterminate leaf/stem and unidentifiable husk. These samples also have the highest densities for cereal husk although the values are not much different to the other samples values. Millet husk has fairly low densities and has its highest density in sample 12 (425). Rice leaf/stem appears in the majority of samples and has its highest values in sample 11 and 13A (2033 and 866). Silica aggregates are much less significant than they appeared to be with relative frequencies.

Grass families

Graphs of the differences in the grass subfamilies from the Orissan sites can be found in figures 7.73 to 7.76. At Bajpur, chloridoid grasses are the most common having the highest densities in samples 1 to 4. Panicoid and festucoid generally have much lower densities although in sample 0 panicoid grasses have a slightly higher density to chloridoid grasses.

There is a similar pattern found at Malakhoja. Chloridoid grasses have the highest densities in samples 1, 4, and 9. Sample 4 has the highest density, which is much higher than the other grass subfamilies. Panicoid grasses have the lowest density in the majority of samples. These first two sites seem to have a similar pattern to that found at Chopani-Mando.

Gopalpur has a very different pattern to that found at Bajpur and Malakhoja but a similar pattern to the mounded sites in the Belan River Valley. Panicoid grasses have the highest densities in the majority of samples: 1-4, 7-11, and 13. Sample 13 has the highest density of these grasses. Festucoid grasses have the highest densities in samples 6 and 12. Sample 13 has the highest density of festucoid grasses overall although panicoid grasses are the highest in this sample. Chloridoid grasses have the lowest densities throughout most of the samples. There is a general rise in the grasses towards sample 13 and then they drop sharply in sample 14.

Panicoid grasses are also dominant at Golbai Sasan. The largest densities are in sample 9 and 11. Festucoid and chloridoid also have their highest densities in these samples. Chloridoid is the largest value in sample 14A and 14B.

Comparing single-celled phytoliths using ratios

At Bajpur, the majority of single-celled phytoliths do not correlate well together. Long smooth and long dendritic have no correlation (see figures 7.77). Bulliforms, keystones, and trichomes correlate well and so do bilobes and crosses but all other combinations of these morphotypes had very little or no correlation.

Long smooth and long dendritics correlate well at Malakhoja as well as bulliforms, trichomes, and keystones (see figures 7.78). Bilobes, saddles, and rondels do not correlate well with each other but seem to correlate with long smooth, long dendritics, keystones, and bulliforms. Saddles have the most correlation with these morphotypes, then bilobes and rondels only have some correlation.

Gopalpur and Golbai Sasan have very similar correlations of the single-celled phytoliths (see figures 7.79 and 7.80). Generally, all the single-celled phytoliths that appear frequently seem to correlate together very well at both of the sites. Long smooth and long dendritics correlate well. Only bulliforms and keystones have slightly less correlation than the others at Gopalpur.

Comparing plant parts using ratios

The lack of multi-celled phytoliths, especially cereal types, at Bajpur and Malakhoja mean that there can be no comparisons of the multi-celled plant parts. This analysis will therefore only be conducted on samples from Gopalpur and Golbai Sasan. The morphotypes used for this analysis are rice bulliforms, double-peaked glume cells, rice bilobes, rice husks, rice leaf/stem, indeterminate leaf/stem, unidentifiable husk, millet husk, and cereal husk. At Gopalpur, the majority of these morphotypes correlate fairly well except for double-peaked glume cell with rice bilobe, rice bulliform with rice bilobe, and rice leaf/stem with rice bilobe (see figure 7.81). Millet husk also does not correlate with any of the other morphotypes. This is the opposite pattern to that found with macro-remains where rice and millet correlate well.

At Golbai Sasan, the same morphotypes have been used in this analysis and they tend to correlate less well than at Gopalpur (see figure 7.82). The rice single-celled and multi-celled phytoliths show mixed results. Double-peaked glume cells correlate well with rice bilobes and rice husks but only have some correlation with the other types. Rice bulliforms do not correlate with rice bilobes, rice husk, and rice leaf/stem. Rice husk generally correlates well with all of the morphotypes except for rice bulliforms and millet husk. Again, millet husk does not correlate well with any of the other morphotypes. Indeterminate leaf/stem and unidentifiable husk correlate well together as well as with the other morphotypes especially rice husk.

7.3 Comparisons of macro-remains and phytolith data

This section will draw together the analysis of the macro-remains and phytoliths and start to make suggestions of general patterns in the dataset. Some attempt is made here to discuss the weed ecology suggested by the plant material found at the mounded sites. Crop processing is investigated and also more general patterns in the data are presented.

7.3.1 Weed ecology

There are not many weeds present in the macro-remain assemblages in this project and many of them have been hard to identify to genus or species level. The weeds that are present only occur in very small numbers. This lack of weeds may be due to the crop being grown or exploited because rice is thought to have less weed infestation than other crop plants (Thompson 1996) although this may only be true of more advanced wetland rice cultivation systems. However, there were some recurring taxa and therefore some implications can be made about the ecology of the possible cultivated fields or areas of collection. A table of the weeds present is found in figure 7.83 with information about their occurrence in the specific study areas and information about their habitat is presented where genus or species is known. At Gopalpur and Golbai Sasan, there is a good correlation between the rice grains and weeds present in the assemblages. Therefore, the weeds present are likely to be associated with the rice crop. It is not as clear with the assemblages from Mahagara and Koldihwa and this may be due to the poor preservation of the macro-botanical material at these sites.

The majority of weeds present in both areas are known weeds of rice crops such as *Ischaemum rugosum*, *Commelina benghalensis*, and Cyperaceae species. Other plants are known to be found in disturbed places, which may also indicate that they are found in agricultural fields. Another strong indicator throughout the weed assemblage is the presence of wet loving taxa. This suggests that the rice crop was grown in a wet environment, which is what would be expected if the crops were to be grown in the local environment of all of the sites. They are all riverine sites and therefore natural floodplains exist close to the sites that are ideal for rice cultivation and would have probably held wild rice populations as has been seen close to the sites today. This indicator of wet environment is also true of the phytolith assemblages, which consistently contained Cyperaceae multi-celled panels. However, these were not particularly well correlated with the rice phytoliths except for at Gopalpur ($R^2 = 0.8528$) and therefore the majority of these remains may not be rice weeds.

There are also a number of taxa that suggest dry conditions such as *Tridex* sp. and these may relate to the other crop plants found at the sites, which could be cultivated in drier conditions than the rice crop or come from another source such as being brought in by animals. Some of the plants are common pasture plants and this may suggest their use as a fodder plant as animals are present at all of the mounded sites.

The large grass found at Gopalpur, which has not been identified, is the only weed to occur in fairly large numbers. The identification of this grass would help to suggest where it may have come from and whether it was exploited as a fodder plant, whether it was eaten by the people at this site, or it may just have been another weed of the rice crop.

7.3.2 Investigation of crop processing

Results of the analysis of crop processing activities is presented here along with some interpretations although more discussion of these results and what they mean is included in the next chapter especially suggestions on the social organisation of the sites.

Traditionally, macro-remains would be used to investigate the crop processing activities on an archaeological site. However, it is clear in this project that preservation of macro-remains is a problem especially at the Belan River Valley sites and therefore these datasets can not be relied on for comparing plant parts. Little or no rice chaff is present at the sites in this project and it can not be suggested accurately that this means that early processing waste was definitely not present on the sites originally because of this preservation issue. Therefore, phytolith analysis is being used here to overcome the preservational biases of macro-botanical remains.

It is clear from the phytolith assemblages that leaf and stem parts of the rice plant are present in the majority of samples, which is an indicator that some of this plant material must have been brought on to the site. Earlier in this chapter correlations have been done between the different rice phytolith parts. These had mixed results such as Koldihwa that had some rice phytoliths that correlated well and others that did not. At Mahagara, Gopalpur, and Golbai Sasan the rice phytoliths seem to have more correlation than has been found at Koldihwa. This may be because the later site is made up of a number of different periods, which may have differences in processing. The other sites are generally of one period.

Further analysis can be done using ratios of leaf/stem to floral parts of the individual samples, which may give more detail of change over time. Graphs of the ratios for rice phytoliths comparing the leaf and floral parts are shown in figures 7.84 and 7.85. The lower the ratio value, the more rice husk is present and therefore less early processing waste is being brought on to the site. This analysis gives some interesting results for the sites and does seem to show a change at Koldihwa. Mahagara generally shows quite high ratios with most of the ratios being over 0.5. This means that there are more equal amounts of leaf/stem and husk or even more leaf/stem than husk parts of rice. Koldihwa demonstrates the same high ratios for the earlier levels at the site but there is a significant change in the Chalcolithic phase to lower ratios. This is seen in both the sections that were sampled. At Gopalpur and Golbai Sasan, there are generally low ratios being under 0.5. A few samples at Gopalpur have higher values but these may just be specific to a type of context with high leaf/stem parts. Further interpretations of these differences will be discussed in the next chapter.

7.3.3 General patterns

There are some interesting patterns within the data set, which are shown in both the macro-remains and phytolith data. The first clear pattern is the difference between the types of sites analysed in this project. There are a lack of seed remains and also charcoal at the sites that have less occupation deposits: Chopani-Mando, Bajpur, Malakhoja, and Banabasa. This pattern is also reflected in the phytolith assemblages as these sites have a lack of multi-celled phytoliths and particularly lack evidence of crop plants such as rice and millets. These sites also demonstrate low values of panicoid grass phytoliths, which suggests less input of these grass types in to these sites potentially meaning less crop plants. Some rice phytoliths have been found at Bajpur but are from the uppermost samples and therefore may be intrusive. In contrast to these more ephemeral sites, the mounded sites (Mahagara, Koldihwa, Gopalpur, Golbai Sasan) have a lot more seeds, charcoal, and phytoliths including crop plants. These sites also have consistently high numbers of panicoid grass phytoliths. There are large amounts of multi-celled phytoliths at these mounded sites, which shows a significant difference to the remains found at the ephemeral sites.

A comparison of the data from macroscopic analysis and phytolith analysis demonstrates a number of similar patterns in terms of the economic plants. This can only be done for the mounded sites because these are the only sites to have large quantities of this material. At most of the sites, there is a great deal of similarity between the macro-remains data and what is found in the phytolith assemblages. A good example of this can be seen at Golbai Sasan, where the samples with the largest amounts of rice grains (especially samples 9 and 11) also have the largest densities of rice phytoliths (see figure 7.86). This is also apparent at Gopalpur, where the dominance of pulse seeds at the bottom of the section is reflected in the lack of rice phytoliths and also generally less phytoliths in these sample overall (see figure 7.87). In samples that have larger amounts of rice grains there are generally higher densities of rice phytoliths at Gopalpur. At Mahagara, there is also a similar pattern of occurrence throughout the section of macro-remains and phytoliths although the densities do not correspond as well as at some of the other sites (see figure 7.88). At Koldihwa, the comparisons are slightly less convincing, which may be due to the lack of macro-remains at this site, although the phytoliths do show the same pattern of increasing density towards the top of the sequences. Section Z1 shows this more than section Y1 (see figure 7.89 and 7.90).

The next chapter draws together all of these results to explore implications about the overall agricultural development and systems employed by these prehistoric peoples. There will also be more discussion about the social implications of this data in terms of crop processing and its effects on labour organisation and settlement patterns. There will also be comparison of this data with other datasets from India and suggestions will be made as to how these areas fit into the world view of agricultural development.

Chapter 8

Interpreting, evaluating data, and concluding remarks

This chapter will bring together all of the issues discussed in this thesis and interpret the data presented in the previous chapter using them. The key issues for this study are what plants are being exploited on these prehistoric sites and are they indigenous crops or introduced from elsewhere. What can the new plant remains tell us about whether these people were sedentary for the whole year or whether the sites were only used in certain seasons. The social organisation of these sites will also be discussed in terms of crop processing activities. The new dataset will be combined with other Indian data to give an insight in to the sub-continent as a whole and how it fits in to the world views of agricultural development.

8.1 Economic patterns

8.1.1 Sites in the Belan River Valley, Uttar Pradesh

Chopani-Mando

The density of macro-remains from all of the sites in the Belan River Valley is disappointing but does illustrate some interesting patterns. Chopani-Mando is devoid of any agricultural remains either macro-remains or phytoliths and only possesses very few remains at all. This is in part due to poor preservation and sample size, which is also seen at Mahagara and Koldihwa in the macro-remains. However, the phytoliths are not subject to these same problems and therefore the lack of organic input in to this site has to be caused by another factor as well as preservation and sample size. This means that it is likely there was very little or no substantial input of plant material and particularly agricultural crops in to this site. Hence, the people at Chopani-mando were not relying on cultivation or collecting large quantities of rice for their subsistence as has been suggested previously from rare finds of rice in pottery. Palmae phytoliths are present throughout the sampled section although only in small amounts and this may suggest the exploitation of some palm species (e.g for hut construction) but this could also be naturally occurring on the site. The phytolith morphotypes present also suggest a dominance of leafy types and this lack of inflorescence types may suggest that this site was occupied at the time of year when there are few flowering plants such as in the dry season. However, this could also mean that they were consciously not selecting for inflorescences and therefore not using large amounts of grasses. Diatoms are also present in the samples and indicates some input from the adjacent meander channel. This may mean that there was seasonal flooding of the site during the monsoon season and again suggests that the site may have only been occupied in the dry season. The severe lack of organic remains suggests this site was occupied for short periods of time allowing any deposited organic material to erode and therefore no continual build up of material was possible. Other evidence from the site also points to non-permanence with little evidence of structures in the later levels and no burials as has been found at similar period sites like those in the middle Ganga Plain.

Mahagara

Mahagara and Koldihwa show considerable differences to Chopani-Mando in their macro-remain and phytolith assemblages. The density of macro-remains is higher at Mahagara and Koldihwa. There are also more multi-celled phytoliths present at these sites as well as higher densities of a larger variety of single-celled phytoliths. These sites show a dominance of panicoid grasses, which include crop plants such as rice and millets. The presence of crop plants as grains and phytoliths is the most important difference from

Chopani-Mando and demonstrates deliberate substantial input of organic remains in to the two mounded sites. The presence of rice as the dominant crop is clear at both of these sites. Rice is present from the beginning of the deposits at Mahagara. Rice phytoliths only appear in small numbers in levels 17 and 15 but become much more prevalent from level 13 to 7. Rice grains are present consistently from level 17 up to level 6. Multi-celled and single-celled rice phytoliths are present rarely at first but become more common in the middle of the section. This suggests this crop was the first to be exploited whether this was collecting of wild stands or cultivation.

Using the phytolith assemblage, some inferences can be made about the crop processing activities at Mahagara and therefore some aspects of social organisation. There are not enough macro-remains to conduct this sort of analysis properly but if these were the only remains that were analysed at Mahagara it might be suggested that the rice grains was being processed off site or even traded in to the site. From the phytolith remains, it is apparent that there are leaf and stem parts of rice throughout the sampled section. Samples 2 and 3 are excluded because they have a different composition to the rest of the samples and therefore suggest a higher density of the later processing waste. The majority of samples from Mahagara demonstrate good correlation between all of the different rice phytoliths suggesting that they were brought on to the site together. This is also apparent from the rice leaf/stem to rice husk ratios, which suggest there are equal amounts of both plant parts. Hence, inferences can be made that the rice was harvested by removing the stem as well as the panicles, which could be from uprooting or by using a sickle, although sickles have not been found at this site but some of the microliths found may have been used for this task. The whole of the rice plant was brought on to the site for processing. This is not surprising because the stem can be as useful as the rice grain. This further suggests that routine processing included basic threshing and dehusking. It can be taken that the people of Mahagara were processing their crops on a more individual basis probably in smaller groups because none of the processing occurred in the field at the time of harvest.

From level 16 at Mahagara, other crops are introduced and this is an interesting development because it includes barley and lentils, which are not native Indian crops. Although, it may be the case that in level 17 the sample size is too small to recover these introduced crops. However, this could also demonstrate a development in the agriculture of the site as has been demonstrated at Senuwar and Lahuradewa, i.e. certain cultivation of domesticates. It probably does suggest a move from one cropping season to two and also a more extensive agricultural system growing a number of different crops in the same season. In these early levels there is no clear evidence of structures and it is not until the middle of the section that there are a number of house plans present. The archaeobotanical evidence does suggest more organic input in to the site in the middle of the section, which seems to coincide with this intensification of settlement. This could be an indication of the shift to year round occupation and possibly an increase in the agricultural production.

The winter crops, however, do not represent a large part of the archaeobotanical assemblage. There are no phytoliths of barley or wheat and this suggests that preservation and sample size were not the only issue for the lack of evidence for these crops on the site. They never appear to become very well established compared to rice, which can be seen in the macro-remains and the phytoliths. This pattern could also suggest that there was a different process happening to the winter crops and particularly wheat and barley. This could include processing off site or even trading in of these crops in a cleaned state, therefore little or no input of waste products on the site. It is clear that the processing of wheat and barley was not a daily activity on the site as was the processing of rice plants.

The phytolith analysis demonstrates that there were probably a number of different sources of plant material coming on to the site. It has been identified above that cultivation was one of these sources and this must have contributed a large amount of phytolith remains including the rice morphotypes but also more general morphotypes such as bilobes, long dendritics, and some of the leafy types. The millet phytoliths identified at Mahagara do not correlate well with the rice phytoliths and this suggests they came from a different source therefore millets could be a separate crop and not a weed of the rice crop. This is also suggested by the macro-remains, which identifies some of the millets as *Setaria verticillata*. This has been demonstrated as an early crop in South India (Fuller 1999, 2002a, Fuller et al. 2004). The fact that most of the single-celled morphotypes do not correlate may suggest a number of sources other than cultivation such as wild collecting, and also the use of dicotyledons, and therefore the use of trees for wood or other domestic purposes. Palmae phytoliths were also present and may suggest another exploited resource but not necessarily for food. It was clear during the analysis that there were a wide variety in the keystone forms and some of these were from reeds, which would be expected on a riverine site and could have also been used for thatching, matting, or basketry.

Koldihwa

There are similar crops present at Koldihwa to those found at Mahagara. Rice, barley, wheat, and pulses are found in the Neolithic phase and most of these are found in the earliest Neolithic deposits. These crops are present throughout the deposits sampled at Koldihwa. Again, the densities for macro-remains are small but there seems to be a general increase in density going up the sequence both for macro-remains and phytoliths therefore moving from the Neolithic to the Chalcolithic phase. Other phytoliths increase going up the sections coinciding with the crop plants such as bilobes, which may suggest they were from the rice plant or from a weed of the crop. Wheat, barley, and winter pulses are only a very small component of the assemblage. There are also no phytolith remains of wheat and barley, which is the same pattern that is found at Mahagara.

This increase in density could be the result of more year round settlement on the site and therefore increased agricultural input. The previous Neolithic period could therefore indicate seasonal habitation maybe to coincide with rice harvesting whether this is of wild rice or cultivated rice, although winter crops are also found in this phase. The shallow depth of the habitational deposits at this site also suggests a less permanent settlement to that seen at Mahagara. There are only two thin layers of the Neolithic phase at Koldihwa compared to the whole of approximately 3 metres of deposits at Mahagara.

With this change in density of plant remains there seems to be an accompanying shift of crop processing strategy. The Neolithic phase has more rice leaf phytoliths present and the rice phytolith ratio is higher for the samples in this period. This demonstrates that the whole of the rice plant is being brought on to the site and suggests a more individual economic strategy because processing is being done at the site in the domestic environment. In the Chalcolithic period there is a large increase in the presence of rice husk on the site and this suggests a shift from the individual processing in the Neolithic to a more communal strategy in which early stages are conducted off-site, or they shifted to being consumers. There are problems with separating these two strategies because of equifinality of their patterns but at this site because of the earlier signs of on-site processing a shift to off-site processing is more likely.

The phytolith assemblage at Koldihwa again suggests a number of different plant sources. Cultivation is probably the predominant source with correlations between the different rice phytoliths, long smooth and long dendritics, and also morphtypes such as bilobes. There is a similar amount of correlation between the phytoliths as has been found at Mahagara. There seems to be more dicotyledon phytoliths present at Koldihwa and also silica aggregates, which can suggest the presence of bark. This may therefore suggest more use of wood as fuel or for other purposes. The keystone phytoliths were observed to be variable as has been found at Mahagara, which suggests a number of different sources such as reeds and other wetland plants. Palmae phytoliths are present sporadically throughout the samples but suggests another resource that could have been exploited. Cyperaceae phytoliths were highest in the lower parts of both sections and therefore show an opposite pattern to the crop plants so are probably not weed crops. These may have occurred naturally at the site or could have been brought to the site for a specific purpose such as fodder.

8.1.2 Sites in Orissa

Bajpur, Banabasa, and Malakhoja

As has been found in the Belan River Valley, there are two types of sites in Orissa. The mounded and later sites of Gopalpur and Golbai Sasan, which show deep archaeological accumulations and are rich in agricultural remains. The other type of site is the more ephemeral sites that are likely to be earlier in date and probably not permanently occupied. These sites (Bajpur, Banabasa, and Malakhoja) are much like Chopani-Mando because the archaeobotanical samples that were taken have produced very little or no plant remains. It was hoped though that even if there were no macro-remains that some evidence could be gained from phytolith analysis. There are phytoliths present in all of the samples taken, however, when these are compared to the mounded sites there is a stark contrast in the morphotypes present. There is less variation in the single-celled phytoliths especially those that may indicate agricultural plants such as bilobes and single celled rice phytoliths. There are also very few multi-celled phytoliths, which indicates that there was a less deliberate input of organic matter in to these deposits or the use of plants that do not produce substantial amounts of phytoliths and are also not likely to be preserved as macro-remains.

Even though this appears to be a disappointing outcome, there are conclusions that can be drawn from these sites. There obviously was human activity during the Mesolithic and Neolithic periods in Orissa as these are not the only sites present in the state (Mohanta 2002). However, this activity was obviously very different to what can be seen in the coastal mounded sites, which are predominantly Chalcolithic in date. This means that these sites are likely not to be permanent as there is no substantial build up of depositional material and also they were probably used for different purposes such as specialised lithic production. Consequently, other places need to be investigated to discover more habitational deposits for these earlier periods. This may include locating new sites and also investigating cave sites (Pradhan 2000), which may have early Neolithic deposits.

Gopalpur

The preservation of macro-botanical remains at Gopalpur and at Golbai Sasan is much better than has been seen at the Belan Valley sites. Both sites have rice and summer pulses present but the main difference from the Belan River Valley is that there are no winter crops present on either site. This is probably due to the extremely high rainfall regime in Orissa and therefore this area is better suited to monsoon crops. This may also suggest that there was little or no contact between these groups in Orissa and those further to the north such as Chirand, which has winter crops present.

At Gopalpur there is evidence of a number of crops both as phytoliths and macro-remains. Rice is present throughout the sampled section and appears to be an important part of the economy at this site. There are also a number of summer pulse crops present. Horsegram and pigeonpea are both present at Gopalpur although horsegram is much more prominent especially in the earlier levels. This may be due to the difference in processing between these two species, which disadvantages the survival of pigeonpea.

There seems to be two phases at the site that can be defined using the archaeobotanical remains. The bottom of the section, therefore the earliest levels, are dominated by the pulse crops although they do also contain rice. From level 6 upwards, pulses decline and there is an increase in the rice grains present and also this is where rice phytoliths start to appear more frequently in the samples. Small millets also appear in larger densities in level 6 and 8 corresponding with the increase in rice grains, which is also highest in these levels therefore the macro-remains correlate well. The millet husk phytoliths do not correlate with the rice phytoliths and therefore this might suggest millet was a minor crop rather than a weed of the rice crop. Gopalpur, therefore, shows a shift from pulses as the dominant crop at the bottom of the sequence to rice, which dominates from the middle of the sequence to the top. Phytolith densities increase going up the sequence and this makes sense because more phytoliths will be produced by rice processing than by the processing of pulse crops. This demonstrates that these phytoliths are predominantly from grasses relating to rice crop most of which are panicoid type.

The majority of samples at Gopalpur suggest a communal strategy for rice processing with limited parts of early stages represented by leaf/stem phytoliths, indicating that these early stages of processing were carried out off site, e.g. at the time of the harvest. Sample 14 and 5 do not fit this pattern and this could result from the specific context that they come from. Both of these samples are hard to compare to the others because they only contain rice bulliforms but did have rice grains so may in fact give a similar outcome if macro-remains and phytoliths are compared. The shift in crop dominance from the bottom to the top does not seem to affect the processing strategy of the rice crop.

The phytolith morphotypes generally correlate well at Gopalpur. This suggests that they had a similar source. It is obvious that a large amount of the plant material is related to the rice crop. However, there are suggestions of other plant materials such as woody plants from silica aggregates and dicotyledon morphotypes. Palm phytoliths occur in small amounts but this still suggests some exploitation of these plants especially in the later periods of occupation.

Golbai Sasan

Golbai Sasan has similar plant remains to those found at Gopalpur with the addition of *Vigna radiata* and *Vigna mungo* as another pulse crop. Rice is denser at Golbai Sasan than at Gopalpur but pulses also play an important role in the economy of this site. Generally all of the plant types are present throughout the sampled section and there are only changes in the density of the remains. The middle of the sequence (samples 12 to 9) has the highest density of material especially sample 9, which has the largest amount of rice grains and small millets. These samples from the middle of the section contain the majority of rice phytoliths. Above and below these samples there are fewer macro-remains and phytoliths apart from sample 3, which contained large amounts of pulses particularly *Vigna* sp. This demonstrates that the largest amount of organic input and therefore presumably the densest occupation may have occurred in this phase of the site. However, the stratigraphy at this site may be spurious because the new dates on the archaeobotanical material suggest a very short period of occupation. This is unlikely because of the large accumulation of material at this site measuring as much as 6 metres. The material taken for samples in this project could therefore be from material that has washed down the slope and is therefore intrusive from the later deposits. It is hard to suggest if this is true or not and only with further dating will this matter be resolved. It will be assumed at present that the material is not slope wash because the stratigraphy looked definite but a note of caution is put on any interpretations made here.

The rice phytolith ratios at Golbai Sasan are similar to Gopalpur. All of the samples, apart from sample 7A that has a slightly higher ratio, have low ratios indicating later stages of processing waste only. This means that mainly the rice spikelets were brought on to the site, and that the straw was separated either when harvesting or by processing in the field. This can be suggested to indicate more communal labour mobilisation at harvest time with the initial stages of processing such as threshing and winnowing happening off-site.

Phytolith morphotypes generally correlate well, as at Gopalpur. This again suggests that the plant remains are from similar sources. Cultivation is probably the main source of the plant material although there is evidence of woody plants and palms. There is more support for millets as a separate crop as the millet macro-remains and phytoliths do not correlate with rice and therefore suggest separate pathways on to the site.

8.2 Implications for the development of agricultural societies in Northern and Eastern India

8.2.1 Belan River Valley

In terms of the development of agricultural societies, this new data goes some of the way to address the important issues in Northern and Eastern India. The sites of Chopani-Mando, Koldihwa, and Mahagara have been previously thought to show a transition from wild rice cultivation to domestic rice agriculture. This is not an accurate interpretation of these sites. To start with the dating of Chopani-Mando is still an issue and the lack of archaeobotanical remains found in this project has not allowed new dating, which is needed to make further interpretation about the chronology. If we are to believe the previous date of ca. 3500 BC then there is a considerable time gap between Chopani-Mando and the later mounded sites of Koldihwa and Mahagara. This does not suggest a continuation of the tradition or a transfer of information. It has also been proposed earlier that the crude pottery found at Chopani-Mando is not related to the pottery found at the later sites. Again this demonstrates that there is unlikely to have been contact between these two cultures or direct continuity between these two phases. The new samples taken from Chopani-Mando suggest that this was a seasonally occupied site and therefore no substantial build up of organic material occurred. Hence, there is no evidence for wild rice cultivation or even substantial exploitation of wild stands at this site. It is also proposed here that Chopani-Mando is not a similar site to Damdama and Sarai-Nahar-Rai, as has been previously suggested (Sharma et al. 1980a), because the remains are different and much less suggestive of any permanent settlement at the former site.

The beginning levels of a number of sites in the Ganges plain suggest an embryonic 'Neolithic' society. The earliest levels of these sites are likely to be seasonally occupied and do not have evidence of a fully developed agricultural system. This is demonstrated at Lahuradewa and Senuwar where the beginning of the occupation has less structural evidence and only rice present (with some weed seeds too). This may mean that at this point wild rice was being harvested and may not have been managed by these groups or some cultivation as part of a system of seasonal mobility. Mahagara may well have a similar beginning to these sites as there is no clear structural evidence until the middle levels of the site and the plant remains suggest rice exploitation from the very beginning although other crops do appear slightly later. The dating from Mahagara suggests that this site began later than Lahuradewa and Senuwar. This time lapse could result from the slow spread of this culture eastwards and south.

The most apparent and significant change that can be seen through the present evidence is the development of permanently settled agricultural societies in this region.

This seems to occur in the later 'Neolithic' when a year round crop package is established and this introduction of winter crops play a key role in the development of a more settled lifestyle. This is the second phase at a number of sites (Lahuradewa, Senuwar, and Mahagara) but a large number of sites in Northern India seem to emerge at this particular time. The majority of these sites continue to develop with the addition of copper and new pottery wares therefore demonstrating a continuation from a developed 'Neolithic' culture to a 'Chalcolithic' phase with much of the same elements persisting.

The winter crops must have travelled across from Northwest India as they have been found at Mehrgarh in Baluchistan by ca. 6000-7000 BC. It seems more likely that there was a piecemeal diffusion of these crops in the Ganges Valley rather than the migration of groups in to the area with these crops as has been previously suggested by some scholars (Saraswat 2004). At Lahuradewa (IB – from about 2500 BC), some pottery forms of Harappan inspiration, such as dish-on-stand, have been found indicating culinary diffusion. However, these forms do not seem to be present at Mahagara. This may suggest that Mahagara just took on the plants from an indeterminate cultural group and not any pottery forms or could suggest that winter crops were not an important parts of the diet, as has been indicated by the new archaeobotanical data, and therefore there was no need for the adoption of new pottery forms.

At Koldihwa, the Neolithic phase starts with summer and winter crops but does not seem to be a fully permanent site because the archaeobotanical material is not particularly dense and there are no substantial structural elements. Therefore in this phase the people used the site seasonally. It is not until the Chalcolithic that the archaeobotanical remains increase suggesting more organic input and year round occupation is more likely to occur during this phase.

There also seems to be a shift in strategy from the Neolithic to the Chalcolithic. The deposits at Mahagara and also the Neolithic deposits at Koldihwa suggest a more focused processing strategy where the whole of the crop is brought on to the site for storage with routine processing by small scale groups. This is in contrast to the Chalcolithic phase at Koldihwa that has a more communal emphasis and therefore an absence or few remains of early processing waste. This indicates a significant change in social organisation. This coincides with the establishment of a more permanent settlement at Koldihwa and may mean that the increased labour of a year round agricultural regime needs more co-operation and therefore more communal effort. Although at Mahagara, this change to more permanent settlement in the middle of the site is not accompanied with a shift in processing strategy. This may mean that this is a difference between 'Neolithic' groups and 'Chalcolithic' groups or could suggest that this was a choice made by the people of Koldihwa, which may have coincided with an intensification of their agricultural economy. At present, it can not be assumed that there is the same pattern for other similar sites in the Ganges Valley as much more archaeobotanical work is needed before this can be confirmed.

Both of these sites have faunal evidence including domestic cattle, domestic sheep/goat, equids (only at MGR), antelope, wild boar, tortoise and also fish. There is also the evidence from Mahagara of cattle hoof-prints from a feature interpreted as a cattle pen by the excavators. Hence, the prehistoric people were engaging in a complex economic system including cultivating plants, rearing animals, hunting wild animals, and fishing. This may have involved the seasonal movement of some groups, such as at Koldihwa, and eventually led to the establishment of settled communities with the introduction of a more complex year round agricultural system with indigenous and introduced elements.

8.2.2 Orissa

The evidence produced in this project from Orissa has started to address questions of the development of agricultural communities and suggestions can now be made as to how this region of India fits in to the prehistory of the sub-continent. At this point it seems that Orissa was behind in agricultural terms to the people of the Ganges Valley. The Neolithic sites sampled in this project provide no indications of agriculture although this may be the result of the use of the sites for more specialised activities rather than domestic purposes. However, the sites in northern and central Orissa do appear to be seasonally occupied because of their lack of substantial deposits much like Chopani-Mando. This does suggest a contrasting lifestyle to the later settled sites found in the coastal plain and therefore a different economic strategy must have been in place. What this strategy was is open to speculation at present and much more sampling of different sites and probably larger sample sizes are needed to help recover some archaeobotanical remains from these earlier sites. It could be suggested that these societies are mobile foragers, which do not exploit grasses therefore they probably rely on forest resources or other non-grass staples such as roots and tubers.

There is a huge contrast in the evidence found at the coastal mounded sites in Orissa. Although, these sites are thought to have Neolithic deposits, it is unlikely that these were sampled in this project because of their restricted area. In some ways, this is similar to Mahagara where there is a lot less structural evidence in the early levels. However, the majority of the deposits at the Orissan sites and those that have been sampled here are Chalcolithic in date. This is reflected by the plant evidence found, which suggests agriculture from the beginning of the sampled sections at Golbai Sasan and Gopalpur. Rice and summer pulses dominate the deposits at both sites and are present in substantial amounts to suggest that they were being cultivated. There is also faunal evidence from both sites, which has been reported as domestic cattle, domestic sheep/goat, and wild animals such as elephant, deer, bear, and antelope. There is further economic evidence in the form of fish bones, which suggests river and sea fishing. All of this evidence suggests a complex economic system of cultivated summer crops, the rearing of domestic animals, hunting wild animals, and also fishing.

A communal processing strategy is suggested for the rice crop at these sites and may be the result of a more intensive agricultural regime. There are no winter crops present on these sites and therefore all of the agricultural work occurred in a restricted time of year during the monsoon period although this does not mean that this was the only time labour was needed because foraging, hunting, and fishing may have occupied the winter months. However, the production of the rice crop and also pulse crops during the summer would have put a lot of pressure on the labour force and may be the reason for communal co-operation and combined effort at this time of the year.

Another issue that must be considered at Golbai Sasan and Gopalpur is what would have been used as a food plant source in the winter because all of the crops are produced in the summer months. This suggests that storage of these crops would have been needed to last the winter or may mean that there is another food source but it has not appeared in the archaeobotanical record. There is evidence of storage jars at Gopalpur, which could have been used to store cereals although no such jars have been found at Golbai Sasan. Possible winter food sources are fruits, green vegetables, and roots and tubers, which can be harvested throughout the winter months (Pratap 2000: 79-80). All of these plants are hard to identify and rarely preserve archaeologically therefore it will be difficult to find evidence of these possible resources.

The lack of winter crops is an interesting pattern. At the start of the project it was expected that winter crops would be found in Orissa because they are found at Chirand in

Bihar to the north of Orissa and links have been made between the pottery wares of sites in Orissa and Bihar. There could be a number of reasons for the winter crops not travelling down to Orissa. There may not have been any contact between sites in Bihar and those in Orissa. As has been seen in this project, there are not substantial Neolithic/ Chalcolithic sites in Northern Orissa and this may have hindered the transportation of this crop package to the Southern Orissan sites. The mountainous region of northern Orissa where different economic regimes are likely to those in the south may have acted as a barrier preventing the spread of these crops. Another reason may have been the climate in this region, which has more rainfall, especially in the monsoon period, than is found in the Ganges Valley. This means that there is less likely to be any problems with producing monsoon crops. Therefore these prehistoric groups had no need to use winter crops. The spreading of agricultural production throughout the year could be a risk-buffering strategy for the Vindhyan culture sites in the Ganges Valley and those in Bihar (like Chirand).

The dominance of summer crops in Orissa is much like the evidence found in South India, where pulses and millets dominate early farming sites. The pulses present are the same as found in the Neolithic Ashmound Tradition sites (horsegram and *Vigna radiata*) but have the differences of *Vigna mungo* and pigeonpea (*Cajanus cajan*). These pulses are rare and late in South India. *Vigna mungo* and *Vigna radiata* are both present at Golbai Sasan and horsegram is present at both the mounded sites. *Vigna radiata* and horsegram could possibly be domesticated in this region but the true area of wild progenitors is still rather unknown and therefore multiple regions could have first exploited these crops. This may alternatively suggest that there was contact between the prehistoric Orissan people and the groups from further South in India as there are larger areas containing the wild progenitors on the Western Ghats (wild *V. radiata*) and Peninsula in general (wild horsegram). *Vigna mungo* is more likely to have been domesticated in the northern Peninsula or western India and then spread eastwards.

An exciting discovery in Orissa is the presence of pigeonpea at Golbai Sasan and Gopalpur. This is a likely domesticate from this region and is the first evidence from prehistoric sites in this state. These sites are not within the modern day distribution of the wild progenitor, although very close to it, and therefore this evidence suggests that these must be cultivated crops whether domestic or wild. The earliest of these pigeonpeas from Gopalpur has been dated directly to 1395 Cal. BC. Pigeonpea is a later addition to South Indian Late Neolithic sites such as Sanganakallu in the mid-second millennium BC (Fuller 2003a), where it dates to 1400-1300 BC, which again suggests that there may be contact between Orissa and regions to the South.

The question of rice domestication in India is still in debate and this thesis has made some strides towards concluding this matter. Rice has been found at all of the mounded agricultural sites sampled and it was the predominant crop in both regions. This strengthens the case for early rice exploitation and presumably cultivation although cannot resolve conclusively whether the rice was wild or domestic. The methodological study of rice identification methods has demonstrated that it is very difficult and probably impossible to distinguish wild and domestic species of rice in the Sativa complex using only a few characteristics even on modern reference material. This is only made more difficult when trying to apply these methods to archaeological material and therefore the way that this problem is approached needs to be rethought. The presence of small wild rice species and ability to distinguish them from the Sativa complex is an interesting development. These species could be used as food or may be weeds of the rice crop. It would be interesting to look in future for when these species first appear and even disappear at sites.

It is quite clear that rice is being exploited throughout Northern and Eastern India in the Neolithic and Chalcolithic periods. The density of material at these sites suggests substantial harvesting and this could result just from wild procurement. However, the introduction of other known cultivated plants such as wheat, barley, and pulses in to these areas suggests a more developed economic strategy than gathering. This could still mean that wild rice is being cultivated and managed, which probably did occur for a very long time due to the potentially slow rate of evolution in rice populations, since rice more readily cross-pollinates compared to Near Eastern cereals. The cultivation of wild rice in the same habitat as wild stands would further prolong the genetic change to domestic species as well as the harvesting methods used. With rice domestication, and probably all of the cross-pollinating crop species such as some millets, it is better to try to identify when wild cultivation began rather than the point of genetic domestication because there is likely to be a large time gap between the two. This can be approached in a number of ways such as looking in more detail at changes in weed floras, and also trying to look for changes from immature to mature grains, which suggests changes in the shattering nature of the plant and hence identifies the genetic change to domestication. Some of the archaeological rice grains in this project are likely to be immature suggesting wild rice was being cultivated.

8.3 Pathways to agriculture and India as part of the world view

The evidence gathered in this project has made it clear that India is definitely very diverse in terms of agricultural development. It needs to be thought of as an equally important area to any other world regions and has a wealth of evidence to be studied. This makes it a very interesting region to study and there are still many avenues of investigation to be studied.

The pathway towards agriculture that was taken by the prehistoric people in the Belan River Valley can be further envisaged using the evidence in this project. Pottery seems to be an early development in this area with evidence coming from Chopani-Mando and also a number of other Mesolithic sites. The dating of this is still not clear but it was definitely part of this earlier Mesolithic phase prior to the development of the Neolithic culture in this region. The next developments are plant cultivation and animal herding that seem to appear at about the same time at the beginning of the 'Neolithic' phase. At this point, the communities are probably seasonally settled to coincide with the rice growing season in the monsoon period. With more advances in the agricultural systems and particularly the adoption of a double-cropping economy, these Neolithic people eventually became fully settled in year-round villages.

It is still hard to form a complete picture of what is going on in Orissa because much more work is needed. However, with the current evidence suggestions can be made about the pathway towards agriculture in this region. The Mesolithic and Neolithic periods in Orissa are still somewhat unknown and there has been a lack of new archaeobotanical evidence found in this project. It has become clear that the Northern highland sites existed on a different economic system and pottery was used at some of the sites. Therefore pottery seems to be the first development towards agriculture at least at the lowland sites. The Neolithic phases definitely seem to be mobile or semi-sedentary. There is still no evidence for plant cultivation or animal herding in the Neolithic so this seems to first occur in the Chalcolithic along with settled sites. There must be evidence in the Neolithic for the beginnings of plant cultivation and also possibly animal herding as has been seen in the Ganges Valley but more sampling is needed to confirm this.

What is clear from both areas is that there is evidence for local domestications such as pigeonpea, other pulses such as *Vigna mungo*, and potentially rice even though these might be fairly late in date compared to other areas of origin. There is also evidence for the introduction of crops such as the Near Eastern crops, which seems to have been added to the existing rice cultivation system in the Ganges Valley. These regions have presented evidence for important agricultural developments in Indian prehistory.

8.4 Methodological issues and further work

The combination of macro-botanical and phytolith analysis worked well to address the questions proposed in this project. Macro-botanical remains were generally readily identifiable to at least genus level and did occur in reasonable amounts at the majority of sites. There is, however, definitely a problem of preservation particularly at the sites in the Belan River Valley. This may in the future be overcome to some extent by increasing the size of bulk samples but it was quite clear that degradation of organic remains is more prevalent at sites in India. This could be a result of the climatic regime, which fluctuates between warm and wet conditions but could also result from other taphonomic issues such as the crops used in these areas and also crop processing methods. It has been suggested by Thompson (1996) that rice grains are less likely to be present on archaeological sites as it does not come in to contact with fire as much as some other crops such as glume wheats. However, this does not seem to play a role here because rice was consistently the most prevalent macro-remain at all of the agricultural sites and appeared in fairly large numbers at Golbai Sasan.

It is definitely beneficial to use phytolith analysis as well as macro-remains to examine the development of agricultural societies in this region because it adds more information to the debate. The small amount of macro-remains meant that detailed analysis could not be relied on for examining crop processing stages. Therefore phytoliths were used and this gave a good insight in to how strategies on each site were different and where there were changes over time. It also allowed identification of other plants that were not seen in the seed assemblage such as palms. However, there are problems that still need to be resolved in phytolith analysis. The most important is problems of identification. The study of rice identification methods has demonstrated that there are problems of using phytoliths to identify rice to species although they can be generally used to identify to genus level. It would also be beneficial to work on identifying other crop plants more accurately such as millets, pulses (although phytoliths are not found in great quantities in these plants), and associated arable weeds. The addition of another analytical method such as starch analysis will help to identify different plant types further and is something that should be attempted in further work in this region.

The rice identification study, although being an important step forward, did bring rather disappointing results. The difficulty of identifying domestic rice is frustrating because being able to distinguish wild from domestic rice would add to the information about early agricultural communities in India. It is clear now that this particular question must be approached from a different angle. Studies looking at different basic cultivation regimes, such as the wild cultivation of rice, wet rice agriculture, and dry rice agriculture needs to be conducted to look at changes in agricultural systems. This can start to identify signatures that can be used to identify different regimes in prehistory including changes in weed flora and crop processing ratios. It is the beginning of cultivation that needs to be identified and also changes in economic systems because these are associated with fundamental changes in prehistoric society such as increased sedentism and the restructuring of social organisation.

To gain further insight in to the social aspects of the early farming communities a much more detailed sampling strategy would be needed and this could only be conducted if full excavation took place. The mounded sites in Orissa would benefit from this, especially Gopalpur, as no previous stratigraphic excavations have taken place and the mound is being slowly taken over by rice paddies. The sampling of more sites in Orissa is needed to create a better understanding of the economic systems in place throughout the diverse environments in the state over different periods of time. Only with more detailed environmental work will Orissa start to play a significant role in the prehistory of India as a whole.

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Appendix 4.1: Table of published archaeobotanical data from Ganges and Orissan sites.

Site	Date or Period	No. of samples	Taxa present	Reference
Atranjikhera, UP	c.2200-600 BC	-	**C**: H Os T **P**: C La Le Pi	Buth & Chowdury 1971, Kajale 1991
Baidaipur, Orissa	Neolithic	-	**C**: Osh	Vishnu-Mittre 1989
Barudih/Singbhum, Bihar	Neolithic	-	**C**: Os	Kajale 1991
Barundha, UP	Neolithic	-	**C**: Or Os	Kajale 1991
Chirand I, Bihar	Neolithic	-	**C**: H Op Or Os T **P**: La Lc Pi V	Vishnu-Mittre 1972
Chopani-Mando III, UP	Adv Mesolithic	-	**C**: Ow	Kumar 2000-2001
Damdama, UP	10,000-3000 BC	-	**C**: Os **O**: ww (1)	Kajale 1990
Golbai Sasan, Orissa	2100-1100 BC	-	**C**: O **P**: M	Sinha 2000
Hulaskhera, I, UP	700-500 BC (BSW)	5	**C**: El H Os **P**: V **O**: ww (3)	Chanchala 1991-1992
Hulaskhera, II, UP	500-200 BC (NBPW)	1	**C**: Ec H **O**: ww (1)	Chanchala 1991-1992
Imlidh-Khurd, I, UP	Neolithic?	-	**C**: B El H Os Pe Se So T **P**: La Lc Pi V **O**: Br Sm ww (3) Z	Saraswat 1992-1993
Imlidh-Khurd II, UP	Chalcolithic/Narhan 1300-800 BC	-	**C**: El H Os Pa Se T **P**: C Lc Pi **O**: ww (4)	Saraswat 1992-1993
Kakoria, UP		-	**C**: Or Os	IAR 1981-82
Kausambi, UP	600-450 BC	-	**C**: H T **P**: Pi **O**: G Z	Chanchala 1995
Khairadih I, UP	Chalcolithic		**C**: O	Singh 1987-88, IAR 1985-86
Khairadih II, UP	700-200 BC		**C**: H Os T **P**: C La Pi V	Singh 1987-88, IAR 1985-86
Koldihwa I, UP	Neolithic	-	**C**: O	Misra 1977b
Koldihwa II, UP	Chalcolithic	-	**C**: Os	Misra 1977b
Koldihwa III, UP	Iron Age	-	**C**: Os T **P**: V	Misra 1977b
Koldihwa I, UP	Neolithic	-	**C**: On Or Os	Vishnu-Mittre IAR 1975-76
Kuchai, Orissa	Neolithic	-	**C**: Ow	IAR 1961-62
Kunjhun, UP	Neolithic	-	**C**: O **P**: M V	Kajale 1991
Lahuradewa IA, UP	6^{th}-5^{th} mill BC	-	**C**: Or Os	Tewari et al. 2002-2003
Lahuradewa IB, UP	4^{th} mill BC	-	**C**: H Or Os T **P**: Lc Pi	Tewari et al. 2002-2003
Lal Qila,	c. 2^{nd} mill BC	-	**C**: H Os T **O**: Cc ww (1)	Kajale 1991, Kajale & Deotare 1993
Lekhania, UP	c. 3^{rd} mill BC	-	**C**: Or Os	Kajale 1991
Mahagara, UP	Neolithic	-	**C**: Or Os	IAR 1981-82

Appendix 4.1 continued: Table of published archaeobotanical data from Ganges and Orissan sites.

Site	Date or Period	No. of samples	Taxa present	Reference
Malhar I, UP	Pre Iron Age 2150-1600 BC	14	**C** : Cl H Or Os Pa Ps Se T **P** : La Lc Pi Vi V **O** : ww (2)	Saraswat 2003-2004
Malhar II, UP	Early Iron Age 1700-800 BC	26	**C**: El H Os Pa Ps So T **P**: La Lc M Pi Vi V **O**: ww (11) Z	Saraswat 2003-2004
Manjhi II, UP	600-50 BC	3	**C**: Ec El H Os Ps Se T **P**: La Lc Pi Vi V **O**: Sm Vv ww (16)	Chanchala 2000-2001
Manjhi III, UP	50 BC – AD 300	1	**C**: Ec El H Os Pa Ps Se T **P** : La Lc Pi Va Vi V **O** : Br Vv ww (18) Z	Chanchala 2000-2001
Narhan I, UP	BRW 1000-800 BC	32	**C** : Ec H Os Pa Pe Ps T **P** : C La Lc M Pi Va Vi V **O**: Br Cc Ln Ph Sm ww (23) Z	Saraswat et al. 1994
Narhan II, UP	BSW 800-600 BC	17	**C**: H Os **P**: Ca Pi Vi V ww (1)	Saraswat et al. 1994
Narhan III, UP	NBPW 600-200 BC	5	**C** : H Os Ps T **P** : La Pi V **O**: Sm ww(1) Z	Saraswat et al. 1994
Narhan IV, UP	Kushana 200 BC – AD 400	1	**O**: G	Saraswat et al. 1994
Oriup, Bihar	Neolithic	-	**C**: Os	Kajale 1991
Pandu Rajar Dhibi I, Bihar	2nd mill BC Neolithic	-	**C**: Osh	Kajale 1991, IAR 1984-85
Radhan, UP	PGW + NBPW	-	**C**: H Os **P**: Pi	Kajale & Lal 1989
Raja-nala-ka-tila I, UP	1600-1300 BC	-	**C**: El H Os Pa T **P**: La Lc Pi V	Saraswat 2004-2005
Raja-nala-ka-tila II, UP	1300-700 BC	-	**C**: El H Os Pa So T **P** : C La Lc M Pi Va V **O**: Al Br Ca Ln Sm	Saraswat 2004-2005
Senuwar IA, Bihar	Neolithic 2200-1950 BC	52	**C**: Cl El H Os Pa Se So T **P**: La Lc Pi Vi **O**: ww (4) Z	Saraswat 2004
Senuwar IB, Bihar	Neolithic- Chalco 1950-1300 BC	54	**C**: H Or Os Ps Se So T **P**: C La Lc M Pi Vi V **O**: Cc ww (4) Z	Saraswat 2004
Senuwar II, Bihar	Chalcolithic 1300-600 BC	40	**C**: El H Os Se So T **P** : C La Lc M Pi Va Vi V **O**: Br Ca Cc Cn Sm ww (8) Z	Saraswat 2004
Sohgaura, UP	c. 2nd mill BC	-	**C**: H	Kajale 1991
Springaverapura, UP	1500-1000 BC	-	**C**: H Os **O**: G Sm	Saraswat 1986a

Appendix 4.1 continued: Table of published archaeobotanical data from Ganges and Orissan sites.

Site	Date or Period	No. of samples	Taxa present	Reference
Taradih, Bihar	Chalcolithic	-	**C**: H T **P**: Lb Le M Pi V **O**: Z	IAR 1981-82, Kajale 1991
Tokwa, UP	Neolithic/Chalcolithic	-	**C**: H Os **P**: V **O**: Br ff (1)	Misra et al. 2000-2001
Waina I, UP	1600-800 BC	-	**C**: H Os Ps Se T **P**: C La Lc M Pi V **O**: Al G	IAR 1994-95, Saraswat 2004-2005
Waina II, UP	800-600 BC	-	**C**: El H Os Se So T **P**: La Lc M Pi V **O**: Br Ca Ln	IAR 1994-95, Saraswat 2004-2005

Key for tables: **C (cereals/ possible cereals)**: Cl (*Coix lachrymal-jobi*), Ec (*Echinochloa*), El (*Eleusine coracana*), H (*Hordeum vulgare*), O (*Oryza* sp.), On (*Oryza nivara*), Op (*Oryza perennis*), Or (*Oryza rufipogon*), Os (*Oryza sativa*), Osh (*Oryza sativa husk*), Pa (*Panicum*), Pe (*Pennisetum glaucum*), Ps (*Paspalum*), Se (*Setaria*), So (*Sorghum bicolor*), T (*Triticum*). **P (Pulses)**: C (*Cicer arietinum*), La (*Lathyrus*), Lb (*Lablab purpureus*), Lc (L*ens culinaris*), Le (*Lens esculenta*), M (*Macrotyloma uniflorum*), Pi (*Pisum sativum*), Va (*Vigna aconitifolia*), Vi (*Vicia sativa*), V (Vigna mungo/radiata). **O (others)**: Al (*Allium*), Br (*Brassica*), Ca (*Carthamus*), Cc (*Curcurbitaceae*), Cn (*Cannabis*), G (*Gossypium*), Ln (*Linum*), Ph (*Phoenix*), Sm (*Sesamum*), Vv (*Vitis vinifera*), Z (*Ziziphus*), ff (other fruits/nuts, with no. of taxa), ww (misc./weeds, with no. of taxa).

Appendix 5.1: Extraction method for phytoliths from sediments.

Day One

i.) Sift the sample through a 0.25mm sieve. Then weigh out 0.8 grams of sieved sample in a plastic tube, recording the weight for later calculations. If you expect the density of phytoliths to be low then you can use about 5 grams of sediment.

ii.) Add 15 ml of 10% HCL to the weighed sample in a fume cupboard and shake gently, leaving cap on loosely after so that gases can escape.

iii.) Make each sample up to 40ml with distilled water and balance them on scales before putting in to the centrifuge.

iv.) Centrifuge for 5 minutes at 2000rpm and then pour off suspense. Repeat this step two more times.

v.) Add a little distilled water and allow to sit over night to disperse the clays.

Day Two

i.) Pipette off the excess water. Then add 20 ml of Sodium hexametaphosphate and shake.

ii.) Transfer to beakers, washing out the tubes thoroughly. Fill up to 8cm mark on beaker with distilled water. Stir well and then wash off stirrer.

iii.) Start the timer once the first sample has been stirred and time for 1hr 10 minutes.

iv.) Pour off the suspense, fill to 8cm with distilled water, stir again and time for 1 hour. Repeat this step until the suspense is clear.

v.) At last pour off leave a little water in the bottom so that the sediment can be transferred in to a crucible with a pipette.

vi.) Once transferred (making sure than the beaker has no sediment left in it), dry in oven at less than 50°C.

Day Three

i.) Take samples out of the oven and break up with a pestle.

ii.) Put in a muffle furnace for two hours at 500°C.

iii.) Remove from furnace and cool.

iv.) Fill tubes with 3ml of Sodium polytungstate solution , which has been calibrated to a specific gravity of 2.3.

v.) Scrape out the crucibles on to a folded piece of paper and then transfer in to the tubes. Close the cap and shake well.

Appendix 5.1 continued: Extraction method for phytoliths from sediments.

vi.) Put in the centrifuge, after balancing on scales, and centrifuge for 10 minutes at 800 rpm.

vii.) Remove tubes and pour off suspense (that has the phytoliths) in to the clean 15 ml tubes. Add distilled water to these tubes with the phytoliths and centrifuge at 2000rpm for 5 minutes.

viii.) Pour off the suspense in to the filtering jar. Add water and wash two more times. Each time save the poured off liquid for later filtering and recalibration.

ix.) Remover the clean phytoliths by pipetting them in to a small container (5 or 10 ml beaker) and dry.

Mounting

i.) Set up mounting equipment in the fume cupboard. Remembering to snap off the end of the pipette because the mounting fluid (Entellan) is very viscous. Label the slides.

ii.) Scrap out beaker and transfer on to slide on scales. If there will be much more than needed (between 2 and 3 mg) then first weigh in to a beaker. Record the whole weight of the phytoliths and also the weight put on to the slide.

iii.) Put a square of Entellan on the labelled slide (the same size as the coverslip).

iv.) Put the weighed phytoliths on the slide and mix in to the Entellan with a toothpick, making sure that they are spread out evenly across the whole slide. Place the cover slip on gently and don't press down. If there are bubbles, then lift the cover slip carefully with the toothpick.

Appendix 5.2: Dry ashing method for making phytolith reference slides.

i.) Separate the selected plant in to the parts needed, e.g; stem, leaf, husk.

ii.) Wash thoroughly with distilled water and cut up the plant parts.

iii.) Place the plant parts in separate numbered boats and record, which part is in each boat (these numbers should be kept throughout the making of slides).

iv.) Put the boats in a 400°C furnace for 2 hours and record their positions so that they don't get mixed up when the labels burn off.

v.) After the two hours, turn off the furnace and allow to cool.

vi.) Transfer the ash into numbered 15ml test tubes and add a small amount of 10% HCL.

vii.) Add distilled water up to 13-14 ml.

viii.) Centrifuge at 2000rpm for 5 minutes. Pour off supernatant with one smooth action.

ix.) Add distilled water up to 13-14 ml. Centrifuge at 2000rpm for 2 minutes. Pour off supernatant.

x.) Repeat last step one more time.

xi.) Transfer the ash pellet to a small beaker and put in a drying oven at below 50°C until dry.

xii.) Then mount on slide with entellan.

Appendix 5.3: Method for preparation of spodograms.

i.) Wash plant material to avoid contamination.

ii.) Trim the plant parts to the desired size so that it fits on to the slide.

iii.) Place the tissue in a petri dish or small beaker and inundate with a 50% bleach solution and allow to stand over night or until tissue is clear or milky.

iv.) Remove tissues from the bleach solution and place in dish of distilled water to rinse it.

v.) Dehydrate with ethanol and then mount on a slide using Entellan.

Appendix 5.4: Description of terms used for phytoliths in the thesis.

Harvey phytolith category	ICPN nomenclature	Notes
Monocot single cells		
Long (smooth)	Elongate psilate – epidermal long cell	Come most from stems
Long (sinuate)	Elongate sinuate – epidermal long cell	Between smooth and dendritic elongates
Long (rods)	Elongate psilate – epidermal long cell	Long and very thin – specific to sedges
Long (dendritic)	Elongate dendriform – epidermal long cell	Not just dendriform but any with larger ornamentation than sinuate. Come from grass floral parts
Papillae	Papillae cell	Anatomical term
Hairs	Hair cell	Anatomical term – long hairs, that would be attached to a hair base
Trichomes	Prickle hair cell	Anatomical term – short hairs, would have no hair base
Bulliform	Parallepipedal bulliform – epidermal short cell	Anatomical term
Ovals	Oval smooth epidermal – short cell	These normally have organic matter attached to them
Keystones	Cuneiform bulliform – epidermal short cell	Also known as fan-shaped bulliforms
Crenates	Tri-lobate – epidermal short cell	-
Bilobes	Bilobate – epidermal short cell	In many various shapes and sizes
Crosses	Quadra-lobate – epidermal short cell	Lots of different sizes
Rondels	Rondel	-
Saddles	Saddle	-
Cones	Conical	-
Flat tower	Conical with flat top	Like a rondel but longer and with a very flat top
Horned tower	Conical with irregular proturberances on top	Like a rondel but longer with spikey top
Rice bulliform	Cuneiform bulliform	Bulliform specific to rice leaves

Appendix 5.4 continued: Description of terms used for phytoliths in the thesis.

Harvey phytolith category	**ICPN nomenclature**	**Notes**
Phragmites bulliform	Cuneiform bulliform	Bulliform specific to Phragmites leaves
Double-peaked glume cell	Bi-echinate - epidermal cell	Specific to rice husks
Rice bilobe	Bilobate concave apexes - epidermal short cell	Bilobe specific to Oryzeae leaves and stem, sometimes called scooped bilobes, arranged horizontally in cell
Dicot single cells		
Rugulose spheroid	Globular echinate	From the Palmae family
Smooth Spheroid	Globular psilate	-
Elongate	Elongate laterally irregular	-
Tracheid	Tracheid	Anatomical term
Blocks	Square regular psilate	Regular flat block shapes
Platey	Irregular shape	Similar to blocks but irregular shapes
Sheet	Irregular shape psilate	Irregular shapes of flat silica panel
Single Polyhedron	Polyhedron shape psilate	Possibly from hair base
Scalloped	Irregular shape	-
Single Jigsaw piece	Multi-lobate irregular pattern	-

Appendix 5.4 continued: Description of terms used for phytoliths in the thesis.

Leaf/Stem: It has the general characteristics of these anatomical parts but can be a large variety of different phytolith panels such as groupings of jigsaw puzzle shapes, bulliforms, panels with a lot of long smooth cells.

Unident Husk: Has to have dendritic long cells and also short cells. Any panels that can not be further identified as other husk are put in this catergory.

Cereal husk: This category is for panels that have the serrated epidermal surface found in rice but do not have the double-peaked husk cells.

Millet husk: At present it is hard to identify millets to genus or species but there seem to be general characteristics for most of the millets. These include varying sizes of the dendritic fingers and also larger papillae.

Phragmites stem: This looks like a grass husk but has thick walls of the wavy dendritic cells. Where the two ends of the dendritic cells meet they are pinched in and between them is a short cell. This short cell is wider than is seen in grass floral parts.

Rice husk: The rice epidermis appears deeply serrated, which is the dendritic cells but they tend to be clumped together and hard to distinguish. This differs from millet husk where the dendritic cells are clearly seen. Double and single peaked hairs are attached to the dendritic cells.

Rice leaf/stem: The rice leaf /stem is easily identified by rows of horizontal scooped bilobes.

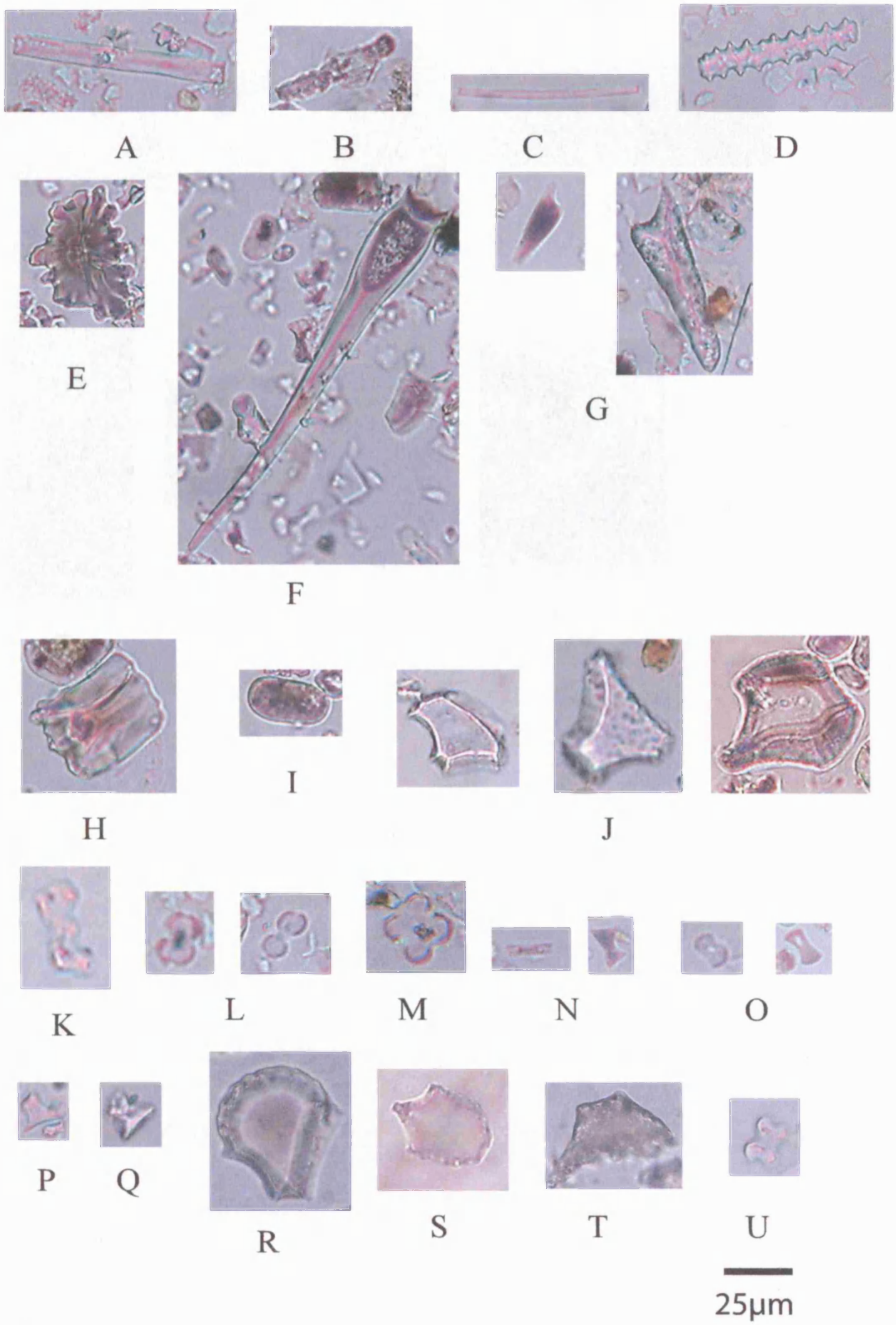
Cyperaceae: These vary but the most commonly occurring in these samples are flat surfaces with cones on them. There are also panels of polyhedral cells, which have cones in the centre and spots on the flat surface.

Square cell leaf/stem: These are blocks of square shaped cells joined together.

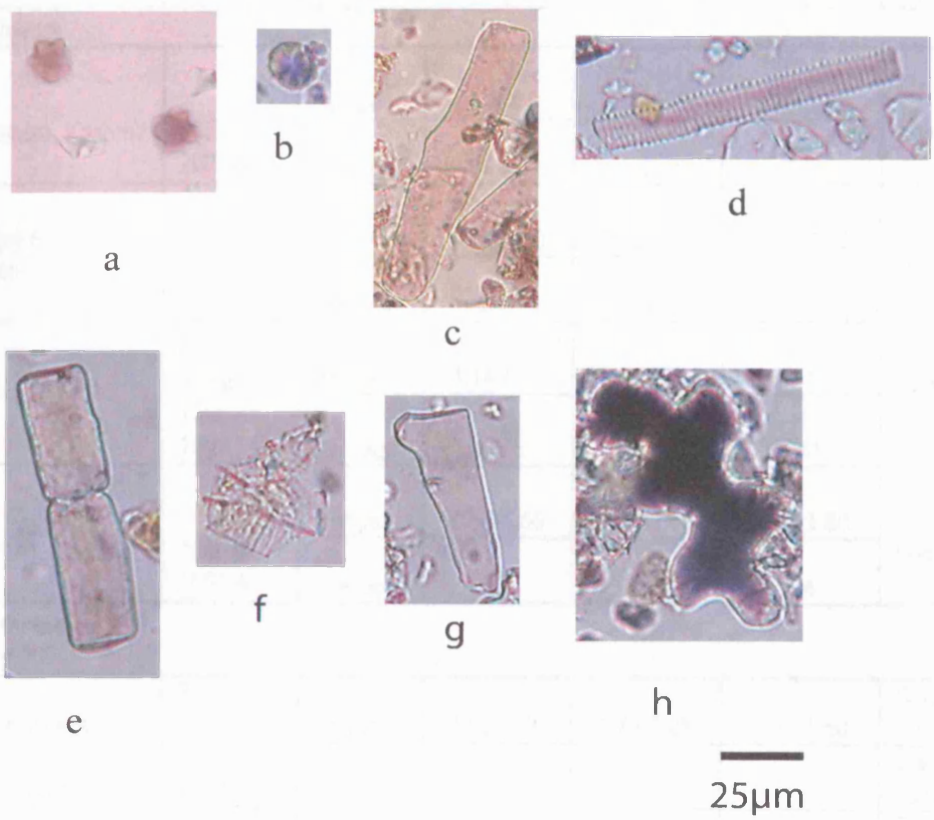
Polyhedral hair base: This is a specific configuration of cells with a hair base sometimes including the hair too, with polyhedral cells around the base.

Mesophyll type: This is specific to the anatomical use of mesophyll layer.

Appendix 5.4 continued: Photographs of phytolith categories in this thesis. Key: A. Long (smooth); B. Long (sinuate); C. Long (rods); D. Long (dendritic); E. Papillae; F. Hairs; G. Trichomes; H. Bulliform; I. Ovals; J. Keystones; K. Crenates; L. Bilobes; M. Crosses; N. Rondels; O. Saddles; P. Flat tower; Q. Horned tower; R. Rice bulliform; S. Phragmites bulliform; T. Double-peaked glume cell; U. Rice bilobe.



Appendix 5.4 continued: Photographs of phytolith categories in this thesis.
Key: a. Rugulose spheroid; b. Smooth spheroid; c. Elongate; d. Tracheid; e. Blocks; f. Platey; g. Sheet; h. single jigsaw piece.



Appendix 6.1: Table of published rice measurements from archaeological sites in South Asia.

Site	Dates	Ave/ range/ per grain	Length	Width	Thickness	Source of data
Northwest						
Burzahom, Kashmir	2375 BC - 200 AD	Range	5.20-4.0	2.50-1.70	1.70-1.10	Lone et al. 1993
		Average	4.5	2	1.2	
Kangra Fort, Punjab	-	Range	4.80-6.20	2.20-2.80	1.80-2.00	Vishnu-Mittre 1974
		Average	5.49	2.45	1.96	
Pirak, Pakistan	Post-Harappan 1950-1550 BC	Range	4.14-4.90	1.85-2.76	1.05-1.52	Costanini 1979
		Average	4.675	2.23	1.31	
Semthan, Kashmir	1500 BC - 1000 AD	Range	4.30-5.50	1.90-2.70	1.20-1.80	Lone et al. 1993
		Average	4.7	2.1	1.4	
Greater Indus Valley						
Balu, Haryana	2500-1900 BC	Range	4.00-5.25	1.75-2.25	1.00-1.50	Saraswat & Pokharia 2001-2002
Chanudaro	2500-2000BC					Vishnu-Mittre & Savithri 1982
Sanghol, Punjab	1900BC-250AD	Range	3.30-5.30	2.00-2.70	1.50-2.00	Saraswat & Chanchala 1997; Pokharia & Saraswat 1999, Saraswat & Pokharia 1998
Sanghol, Punjab	100-300BC - Kushana period	Range	3.30-5.30	2.00-2.70	1.50-2.00	Saraswat & Pokharia 1998
Indo-Gangetic divide/ Gangetic Doab						
Atranjikhera	2000-1500BC	Range	6.00-6.50	3.5	-	Saraswat 1980
Hulas	1800-1300BC	Range	3.30-5.30	2.00-2.70	1.50-2.00	Saraswat 1993

Appendix 6.1: Table of published rice measurements from archaeological sites in South Asia

Site	Dates	Ave/ range/ per grain	Length	Width	Thickness	Source of data
Middle Ganges Valley						
Charda, U P	900BC - 1100 AD pre-NBPW to Medieval period	Range	4.00-5.00	1.00-3.00	1.00-1.50	Chanchala Srivastava 2002
Chirand, Bihar	2200-1500BC	Small range	4.25-4.50	1.50-1.80	1.00-1.00	Vishnu-Mittre 1974
		Average	4.38	1.65	1	
		Large range	5.00-5.25	2.25-2.50	1.25-1.25	
		Average	5.13	2.38	1.25	
Hastinapur, UP	506-306 BC	Range	5.00-7.00	2.00-2.70	-	Vishnu-Mittre 1974
Hulaskera, UP	700 BC - 250 AD	Range	4.00 - 5.00	1.75 - 2.60	1.00 - 1.75	Chanchala 1991-1992
Malhar, UP	1900 - 800 BC	Range	4.50-5.30	2.00-2.50	1.40-2.00	Saraswat 2003-2004
Manjhi, Bihar	250BC-250AD	Range	3.00-5.00	1.25-2.00	1.00-1.75	Chanchala Srivastava 2000-2001
Narhan, UP	1300-300 BC	Range	4.00 - 5.00	1.90-2.20	1.10-1.30	Saraswat et al 1994
Oriyup, Bihar	Neolithic	Range impressions	5.00-5.50	2.25-2.50	-	Vishnu-Mittre 1974
Pataliputra, Bihar	405-115 BC	Range	3.50-5.40	2.50-3.00	2.00-2.50	Vishnu-Mittre 1974
		Average	4.95	2.66	1.82	
Radhan, UP	1000-250BC	Range historic	2.40-3.30	1.10-1.70	-	Kajale & Lal 1989
		Average	2.74	1.45	-	
		Range PGrey/NBPW	2.10-3.30	1.2-1.7	-	
		Average	2.64	1.39	-	
		Grain B	4.4	2.3	1.5	
		Grain C	5	1.8	1.5	
		Average	4.85	2.11	1.5	

Appendix 6.1 continued: Table of published rice measurements from archaeological sites in South Asia.

Site	Dates	Ave/ range/ per grain	Length	Width	Thickness	Source of data
Senuwar, Bihar	2000 BC - 600 BC	Range	3.00-5.30	1.50-2.50	1.30-2.00	Saraswat 2004
Springaverapura, UP	1,050-1,000 BC	Grain A	4	1.8	1.25	Saraswat 1986a
Singhbhum, Bihar	Neolithic	Range	5.00-5.25	2.00-2.25	1.25-1.50	Vishnu-Mittre 1974
		Average	5.12	2.12	1.35	
Sonpur, Bihar	637 BC	Range	4.16-5.54	1.65-2.57	1.40-1.60	Vishnu-Mittre 1974
Rajasthan/Madhya Pradesh						
Ahar	1885-1070 BC	Range	5.00-7.00	2.00-3.00	1.25-2.00	Vishnu-Mittre 1969, Vishnu-Mittre 1974
		Average	6	2.5	1.63	
Garh Kalika	500 BC	Range	4.00-5.50	2.10-2.70	1.00-1.70	Vishnu-Mittre 1974
		Average	4.73	2.49	1.48	
Kaundinyapur	500-200 BC	Range	3.00-4.80	1.50-3.00	1.00-1.50	Vishnu-Mitrre 1974
		Average	3.9	2.25	1.25	
Nagda Ujjain	500-200 BC	Range	4.50-5.70	2.10-2.60	1.50-2.00	Vishnu-Mittre 1974
		Average	4.9	2.47	1.78	
Navadatoli-Maheshwar	1557-1400 BC	Range	4.30-5.10	2.00-2.40	1.20-1.80	Vishnu-Mittre 1974
		Average	4.7	2.2	1.5	
Maharastra						
Bhokardan	300 BC - 250 AD	Range	5.0-2.7	2.8-3.1	1.7-1.9	Kajale 1974
		Average	5.5	3	1.8	
Inamgaon	1600BC-700 BC	Average	2.9	2.3	0.9	Vishnu-Mittre & Savithri 1976, Kajale 1988
Kolhapur	AD 100	Range	3.80-5.40	2.30-2.60	-	Vishnu-Mittre 1974
Navdatoli	1500-1200 BC	Range	4.3-5.1	2.0-2.4	1.2-1.8	Vishnu-Mittre 1961
		Average	4.7	2.2	1.5	
Nevasa	1500 BC-1800AD	Range	2.50-3.90	1.95-1.40	-	Kajale 1977b
		Average	3.24	1.626	-	
Nevasa	1318-1759 AD	Range	3.94-4.74	1.96-2.46	1.28-1.75	Vishnu-Mittre 1974
		Average	4.38	2.18	1.38	

Appendix 6.1 continued: Table of published rice measurements from archaeological sites in South Asia.

Site	Dates	Ave/ range/ per grain	Length	Width	Thickness	Source of data
Paunar	500-400 BC, 300-600 AD	Range	5.00-9.00	1.00-3.00	-	Vishnu-Mittre & Gupta 1968b, Vishnu-Mitrre 1974
Pauni	200 BC	Range	6.00-7.00	2.25-2.50	-	Vishnu-Mittre 1974
Ter	155BC-260AD	Range – grains	3.00-5.00	2.50-2.75	1.00-2.25	Vishnu-Mittre et al. 1971, Vishnu-Mittre 1974
		Range-spikelets	6.00-6.50	2.50-3.00	1.50-2.50	
		Average	5.64	2.47	1.78	
		individual	3.2	2.05	1.2	
		individual	4.5	3.2	1.7	
		individual	3.8	2.4	1.5	
		Average	3.83	2.55	1.5	
Ter	100 BC-3rd C AD	Grain 1	4.5	2	1.5	Kajale 1975
		Grain 2	5.5	2.5	1.5	
Tuljapur Garhi	Chalcolithic	Range	5.20-5.80	2.25-2.60	1.50-2.00	Kajale 1996
Saurashtra						
Kamrej	Early historic	Min	2.4	1.5	1	Kajale 2004
		Max	5.4	3.12	2.18	
		Average	4.47	2.17	1.63	
Lothal, Gujurat	2300BC	Range	5.00-7.00	2.50-3.00	-	Vishnu-Mittre 1974
Rangpur, Gujurat		Range	3.0-4.0	2.5-3.0	-	Ghosh & Lal 1963
Orissa						
Baidipur	Late Neolithic	Range	5.00-5.50	2.25-2.50	1.25-2.00	Vishnu-Mittre 1974
		Average	5.25	2.38	1.63	

Appendix 6.1 continued: Table of published rice measurements from archaeological sites in South Asia.

Site	Dates	Ave/ range/ per grain	Length	Width	Thickness	Source of data
South India						
Hallur, Mysore	870 BC	Range	7.00-8.00	2.00-2.50	-	Vishnu-Mittre & Savithri 1971, Vishnu-Mittre 1974
	1000 BC	Range	2.5-2.9	1.10-1.06	-	Kajale 1989b
		Average	2.62	1.31	-	
Kunnatar, Madras	300 BC	Grain	7	2	-	Vishnu-Mittre 1974
Veerapuram, A.P.	500BC-400AD	Range	3.10-4.20	1.80-2.50	-	Kajale 1984
		Average	4.06	2.24	-	
Kolhapur	1st C. AD	Average sample I	4.8	2.6	-	Kumar 1948
		Average sample II	5.4	2.3	-	
		Average sample III	3.8	2.3	-	

Appendix 7.1: Raw data table for macro-botanical remains from Koldihwa.

	Sample Koldihwa	ABOT 1	ABOT 2	ABOT 3	ABOT 4	ABOT 5	ABOT 6	ABOT 7	ABOT 8	ABOT 9	ABOT 10	ABOT 11	ABOT 12	ABOT 13	ABOT 14	ABOT 15	ABOT 16	ABOT 17	ABOT 18	ABOT 19	ABOT 20
	Level	Z1/1	Z1/1 Pit A	Z1/2	Z1/40cm	Z1/3	Z1/3	Z1/4	Z1/4	Z1/5	Z1/5	Y1/1	Y1/1	Y1/2	Y1/2	Y1/3	Y1/3	Y1/4	Y1/4	Y1/5	Y1/5
		TOP								BOTTOM		TOP								BOTTOM	
	Age by material culture	I/A	I/A	Chalco	Chalco	Neo	Neo	Neo	Neo	Sterile	Sterile	I/A	I/A	Chalco	Chalco	Neo	Neo	Neo	Neo	Sterile	Sterile
	Soil vol. (l)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Sample vol (ml)	60	120	185	50	15	30	8	20	10	5	90	50	30	50	180	120	5	5	5	5
	Density of sample per litre (ml)	3	6	9.25	2.5	0.75	1.5	0.4	1	0.5	0.25	4.5	2.5	1.5	2.5	9	6	0.25	0.25	0.25	0.25
	Vigna sp. (whole)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	Vigna sp. (cotyledon)	1	1	1	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
U	Vigna sp. (frag)	0	0	0	0	0	0	0	1	0	0	2	0	1	3	0	0	0	0	0	0
L	Vigna cf. radiata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Lens culinaris (whole)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Lens culinaris (cotyledon)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Lens culinaris (frag)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Lathyrus sativus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	cf. Lathyrus aphaca	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pisum sativum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cajanus/ Lablab?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pulse frags	1	1	2	0	3	0	0	1	0	0	0	2	0	1	1	1	0	0	0	0

Appendix 7.1 continued: Raw data table for macro-botanical remains from Koldihwa.

	Sample Koldihwa	ABOT 1	ABOT 2	ABOT 3	ABOT 4	ABOT 5	ABOT 6	ABOT 7	ABOT 8	ABOT 9	ABOT 10	ABOT 11	ABOT 12	ABOT 13	ABOT 14	ABOT 15	ABOT 16	ABOT 17	ABOT 18	ABOT 19	ABOT 20
	Bracharia ramosa (hulled) well pres	0	0	0	1	1	1	1	0	0	0	1	4	2	0	0	1	0	0	1	0
C	B.ramosa (caryopsis)	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Setaria verticilliata (hulled) well pres	0	0	0	0	0	0	0	2	0	0	1	0	0	0	1	0	0	0	0	0
R	S. verticillata (caryopsis)	0	0	3	0	0	0	1	0	0	0	2	1	1	0	1	0	0	0	0	0
E	Setaria sp. (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
A	Echinochloa sp. (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
L	Panicum sumatrense (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
S	Panicum sp. (caryopsis)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Paspalum sp. (caryopsis)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
&	Pennisetum (wild) sp. (caryopsis)	0	0	4	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Digitaria sp. (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
G	Indeterminate small millet	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
R	Hordeum vulgare (caryopsis whole)	3	1	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0
A	Hordeum vulgare (caryopsis 1/2)	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
S	Triticum sp. (free-threshing)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	cf. Triticum sp. small	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
E	Oryza sp. (whole caryopsis)	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Oryza sp. (caryopsis 1/2)	0	2	5	3	0	1	0	2	0	0	0	0	0	0	1	0	0	0	0	0
	Oryza sp. (caryopsis 1/4)	3	0	11	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Oryza sp. (glume frag)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Oryza sp. (husk frag)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Unknown Glume bases	0	0	?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Indet. Graminae (caryopsis)	4	11	0	0	0	1	0	1	0	0	3	2	0	2	0	0	0	0	0	0

Appendix 7.1 continued: Raw data table for macro-botanical remains from Koldihwa.

	Sample Koldihwa	ABOT 1	ABOT 2	ABOT 3	ABOT 4	ABOT 5	ABOT 6	ABOT 7	ABOT 8	ABOT 9	ABOT 10	ABOT 11	ABOT 12	ABOT 13	ABOT 14	ABOT 15	ABOT 16	ABOT 17	ABOT 18	ABOT 19	ABOT 20
	Ziziphus sp.	1	0	0	2	0	0	0	0	0	0	4	1	0	1	2	0	0	0	0	0
	Cyperaceae type	0	0	1	0	0	2	0	0	0	0	4	3	0	1	0	0	0	0	0	0
	Malvaceae type	0	0	1	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
W	Malvaceae testa	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Polygonaceae type	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
E	Rubiaceae type	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
D	Schleriaceae type	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Indet culm node	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Indet internode	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Indet pedestal	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Indet striated seed coat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Modern seeds	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Charcoal	xxx	xxx	xxx	xxx	xx	xx	xx	xx	xx	xx	xx	xx	xxx	xxx	xx	x	x	x	x	0
	Shoots	0	Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Indeterminate	2	6	16	5	9	9	3	7	0	0	27	3	1	1	7	6	0	0	0	0
	Total fragments	**21**	**25**	**50**	**14**	**16**	**15**	**5**	**16**	**0**	**0**	**54**	**20**	**8**	**13**	**16**	**11**	**1**	**0**	**1**	**0**

Appendix 7.2: Raw data table for macro-botanical remains from Mahagara.

	Sample Mahagara	ABOT 21	ABOT 22	ABOT 23	ABOT 24	ABOT 25	ABOT 26	ABOT 27	ABOT 28	ABOT 29	ABOT 30	ABOT 31	ABOT 32	ABOT 33	ABOT 34	ABOT 35	ABOT 36	ABOT 37	ABOT 38
	Level	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10
		TOP																	
	Soil vol. (L)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Sample vol. (ml)	8	10	10	15	8	15	10	50	8	10	30	10	20	30	8	10	5	5
	Density of sample per litre (ml)	0.4	0.5	0.5	0.8	0.4	0.8	0.5	2.5	0.4	0.5	1.5	0.5	1	1.5	0.4	0.5	0.3	0.3
	Parenchyma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vigna sp. (whole)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	Vigna sp. (cotyledon)	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1
U	Vigna sp. (frag)	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	1	0
L	Vigna cf. radiata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Lens culinaris (whole)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Lens culinaris (cotyledon)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Lens culinaris (frag)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lathyrus sativus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	cf. Lathyrus sativus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pisum sativum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cajanus/ Lablab?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cajanus cajan (whole)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pulse frags	0	0	0	0	0	0	0	0	1	0	2	1	1	8	2	2	0	0
	Bracharia ramosa (hulled) well pres	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	B.ramosa (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Setaria verticilliata (hulled) well pres	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	S. verticillata (caryopsis)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	2
E	cf. S. verticillata (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
A	Setaria sp. (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7.2 continued: Raw data table for macro-botanical remains from Mahagara

	Sample Mahagara	ABOT 21	ABOT 22	ABOT 23	ABOT 24	ABOT 25	ABOT 26	ABOT 27	ABOT 28	ABOT 29	ABOT 30	ABOT 31	ABOT 32	ABOT 33	ABOT 34	ABOT 35	ABOT 36	ABOT 37	ABOT 38
L	cf. Panicum sumatrense (caryopsis)	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Panicum sp. (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Paspalum sp. (caryopsis)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
&	Indeterminate small millet	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	1	0
	Millet spikelet	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
G	Dactyloctenium aegyptium	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
R	Hordeum vulgare (caryopsis whole)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
A	Hordeum vulgare (caryopsis 1/2)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	cf. Triticum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Free threshing wheat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Oryza sp. (whole caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
S	Oryza sp. (caryopsis 1/2)	0	0	0	0	0	0	0	0	1	1	0	3	1	0	3	0	0	0
	Oryza sp. (caryopsis 1/4)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	3	1
	Oryza sp. (husk frag)	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
	Oryza sativa (glumes)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Oryza sp. (glumes)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Indet. Graminae (caryopsis)	0	0	0	0	0	0	0	0	0	4	1	0	0	3	2	0	0	0
	Ziziphus sp.	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0
	Fruit frag indet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sesamum sp. (wild)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Appendix 7.2 continued: Raw data table for macro-botanical remains from Mahagara

	Sample Mahagara	ABOT 21	ABOT 22	ABOT 23	ABOT 24	ABOT 25	ABOT 26	ABOT 27	ABOT 28	ABOT 29	ABOT 30	ABOT 31	ABOT 32	ABOT 33	ABOT 34	ABOT 35	ABOT 36	ABOT 37	ABOT 38
	Chenopodiaceae type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Commenlina benghalensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	Cyperaceae type	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
E	Cyperaceae cf. Scirpus sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
E	Euphorbiaceae type	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
D	Eragrostis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Ischamemum rugosum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Malvaceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Polygonaceae type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Portulaceae type	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Indet pedestal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Indet small legume	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Modem seeds	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Charcoal	x	x	x	x	x	x	x	xx	xx	x	xx	xx	xx	xxx	xxx	xx	xxx	xx
	Indeterminate	0	2	0	0	0	3	6	4	7	1	4	11	4	17	0	22	3	4
	Total fragments	**7**	**3**	**1**	**0**	**0**	**4**	**9**	**5**	**12**	**10**	**8**	**16**	**11**	**34**	**9**	**30**	**11**	**10**

Appendix 7.2 continued: Raw data table for macro-botanical remains from Mahagara

	Sample Mahagara	ABOT 39	ABOT 40	ABOT 41	ABOT 42	ABOT 43	ABOT 44	ABOT 45	ABOT 46	ABOT 47	ABOT 48	ABOT 49	ABOT 50	ABOT 51	ABOT 52
	Level	11	11	12	12	13	13	14	14	15	15	16	16	17	17
														BOTTOM	
	Soil vol. (L)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Sample vol. (ml)	10	15	10	15	10	20	10	10	5	5	10	10	10	40
	Density of sample per litre (ml)	0.5	0.8	0.5	0.8	0.5	1	0.5	0.5	0.3	0.3	0.5	0.5	0.5	2
	Parenchyma	2	1	0	0	0	0	1	0	0	0	0	0	0	0
	Vigna sp. (whole)	0	0	0	0	0	0	0	1	0	0	0	0	0	0
P	Vigna sp. (cotyledon)	3	0	3	0	1	1	1	1	0	0	1	0	0	0
U	Vigna sp. (frag)	0	0	0	4	0	3	0	0	0	0	1	1	0	0
L	Vigna cf. radiata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Lens culinaris (whole)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Lens culinaris (cotyledon)	0	0	0	1	1	2	0	0	0	0	0	3	0	0
S	Lens culinaris (frag)	0	0	0	2	0	0	1	0	0	0	0	2	0	0
	Lathyrus sativus	0	0	0	0	0	2	0	0	0	0	0	0	0	0
	cf. Lathyrus sativus	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pisum sativum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cajanus/ Lablab?	1	0	0	0	0	0	0	0	0	0	0	1	0	0
	Cajanus cajan (whole)	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Pulse frags	5	3	4	3	2	5	2	4	0	1	0	9	0	0
	Bracharia ramosa (hulled) well pres	0	1	0	0	0	0	0	0	0	0	0	0	0	0
C	B.ramosa (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Setaria verticilliata (hulled) well pres	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	S. verticillata (caryopsis)	1	2	0	1	0	0	0	1	0	2	0	3	0	0
E	cf. S. verticillata (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A	Setaria sp. (caryopsis)	0	2	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7.2 continued: Raw data table for macro-botanical remains from Mahagara

	Sample Mahagara	ABOT 39	ABOT 40	ABOT 41	ABOT 42	ABOT 43	ABOT 44	ABOT 45	ABOT 46	ABOT 47	ABOT 48	ABOT 49	ABOT 50	ABOT 51	ABOT 52
L	cf. Panicum sumatrense (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Panicum sp. (caryopsis)	0	2	0	0	1	0	0	0	0	0	0	0	0	0
	Paspalum sp. (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
&	Indeterminate small millet	3	7	1	0	0	1	0	1	0	0	1	3	0	0
	Millet spikelet	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	Dactyloctenium aegyptium	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	Hordeum vulgare (caryopsis whole)	1	3	0	0	0	0	0	0	0	0	1	2	0	0
A	Hordeum vulgare (caryopsis 1/2)	0	1	0	0	0	0	1	0	1	0	0	0	0	0
S	cf. Triticum sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0
S	Free threshing wheat	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Oryza sp. (whole caryopsis)	5	0	0	0	0	1	0	0	0	0	0	0	0	0
S	Oryza sp. (caryopsis 1/2)	1	2	0	0	3	4	0	2	1	0	0	1	0	1
	Oryza sp. (caryopsis 1/4)	11	8	1	3	5	4	1	2	1	0	1	1	0	0
	Oryza sp. (husk frag)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oryza sativa (glumes)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oryza sp. (glumes)	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Indet. Graminae (caryopsis)	4	5	4	3	10	5	1	0	0	0	1	7	2	0
	Ziziphus sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Fruit frag indet	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Sesamum sp. (wild)	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7.2 continued: Raw data table for macro-botanical remains from Mahagara

	Sample Mahagara	ABOT 39	ABOT 40	ABOT 41	ABOT 42	ABOT 43	ABOT 44	ABOT 45	ABOT 46	ABOT 47	ABOT 48	ABOT 49	ABOT 50	ABOT 51	ABOT 52
	Chenopodiaceae type	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Commenlina benghalensis	0	0	0	0	0	1	0	0	0	0	0	0	0	0
W	Cyperaceae type	0	1	0	0	0	0	0	0	0	0	0	0	0	0
E	Cyperaceae cf. Scirpus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Euphorbiaceae type	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	Eragrostis sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S	Ischamemum rugosum	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Malvaceae	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	Polygonaceae type	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Portulaceae type	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Indet pedestal	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Indet small legume	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Modern seeds	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Charcoal	xxx	xxx	xxx	xx	xx	xxx	xx	xx	xx	x	xx	xx	xx	x
	Indeterminate	11	39	22	8	28	17	8	8	1	19	1	30	0	2
	Total fragments	**52**	**77**	**36**	**25**	**55**	**48**	**16**	**20**	**4**	**23**	**7**	**64**	**2**	**3**

Appendix 7.3: Raw data table for macro-botanical remains from Chopani-Mando.

	Sample Chopani-Mando	ABOT 53	ABOT 54	ABOT 55	ABOT 56	ABOT 57	ABOT 58	ABOT 59	ABOT 60	ABOT 61	ABOT 62	ABOT 63	ABOT 64	ABOT 65	ABOT 66	ABOT 67	ABOT 68	ABOT 69	ABOT 70	ABOT 71	ABOT 72
	Level	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10
		TOP																		BOTTOM	
	Soil vol (L)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Sample vol (ml)	10	20	10	30	15	40	6	5	8	5	10	30	5	15	5	7	3	5	3	5
	Density pre litre of sediment (ml)	0.5	1	0.5	1.5	0.75	2	0.3	0.25	0.4	0.25	0.5	1.5	0.25	0.75	0.25	0.35	0.15	0.25	0.15	0.25
PULSES	Parenchyma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vigna sp. (frag)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Vigna cf. radiata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Len culinaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lathyrus sativus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pisum sativum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pulse frags	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cajanus/ Lablab?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEREALS	Bracharia ramosa (hulled) well pres	8	9	4	5	1	3	1	0	0	0	0	0	0	0	0	0	1	0	1	1
	B.ramosa (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Setaria verticilliata (hulled) well pres	3	1	0	0	0	0	0	0	0	3	0	1	1	0	0	0	0	0	0	1
	S. verticillata (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Echinochola colona	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Panicum sumatrense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Indeterminate small millet	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7.3 continued: Raw data table for macro-botanical remains from Chopani-Mando.

	Sample Chopani-Mando	ABOT 53	ABOT 54	ABOT 55	ABOT 56	ABOT 57	ABOT 58	ABOT 59	ABOT 60	ABOT 61	ABOT 62	ABOT 63	ABOT 64	ABOT 65	ABOT 66	ABOT 67	ABOT 68	ABOT 69	ABOT 70	ABOT 71	ABOT 72
&	Millet spikelet Panicum sp. (wild)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	Hordeum vulgare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	Triticum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A	Oryza sp. (whole caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Oryza sp. (caryopsis frags)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Oryza sativa (glumes)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Oryza sp. (glumes)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Indet. Graminae (caryopsis)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	Cyperaceae	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0
E	cf. Ludwigia sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Modern seeds	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
D	Charcoal	x	x	x	x	x	x	x	x	x	x	0	x	x	x	x	0	x	x	x	x
S	unknowns	2	0	0	0	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	3
	Total fragments	**18**	**11**	**4**	**10**	**7**	**3**	**1**	**0**	**0**	**5**	**2**	**1**	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**5**

Appendix 7.4: Table of ubiquity values for Belan River Valley sites.

Site	KDW		MGR		CPM	
	no of samples	ubiquity	no of samples	ubiquity	no of samples	ubiquity
Parenchyma	0	0%	3	9%	0	0%
Vigna sp.	9	45%	14	44%	0	0%
Lens culinaris	1	5%	6	19%	0	0%
Lathyrus sativus	0	0%	2	6%	0	0%
Pisum sativum	0	0%	0	0%	0	0%
Cajanus/Lablab?	0	0%	2	6%	0	0%
Cajanus cajan	0	0%	1	3%	0	0%
Pulse frag	9	45%	17	53%	0	0%
All pulses	12	60%	20	63%	0	0%
Bracharia ramosa	1	5%	0	0%	0	0%
Setaria verticillata	6	30%	10	31%	0	0%
Setaria sp.	2	10%	1	3%	0	0%
Echinochloa sp.	1	5%	1	3%	1	5%
Panicum sumatrense	1	5%	0	0%	0	0%
Panicum sp.	1	5%	3	9%	0	0%
Paspalum sp.	1	5%	1	3%	0	0%
Pennisetum (wild) sp.	3	15%	0	0%	0	0%
Digitaria sp.	1	5%	0	0%	0	0%
Indet. small millet	3	15%	10	31%	2	10%
All small millets	10	50%	18	56%	3	15%
Hordeum vulgare	5	25%	7	22%	0	0%
Triticum sp.	2	10%	1	3%	0	0%
Oryza sp.	8	40%	23	72%	0	0%
Indet Graminae	7	35%	14	44%	1	5%
All large cereals	13	65%	25	78%	1	5%
Ziziphus sp.	6	30%	3	9%	0	0%
Fruit frag indet.	0	0%	1	3%	0	0%
Sesamum sp. (wild)	0	0%	1	3%	0	0%
Polygonaceae	1	5%	1	3%	0	0%
Chenopodiaceae	0	0%	1	3%	0	0%
Cyperaceae	5	25%	3	9%	2	10%
Cyperaceas cf. Scirpus sp.	0	0%	1	3%	0	0%
cf. Ludwigia sp.	0	0%	0	0%	1	5%
Portulaceae	0	0%	1	3%	0	0%
Euphorbiaceae	0	0%	1	3%	0	0%
Eragostris sp.	0	0%	1	3%	0	0%
Ischamemum rugosum	0	0%	1	3%	0	0%

Appendix 7.4 continued: Table of ubiquity values for Belan River Valley sites.

Site	KDW		MGR		CPM	
	no of samples	ubiquity	no of samples	ubiquity	no of samples	ubiquity
Commenlina benghalensis	0	0%	1	3%	0	0%
Malvaceae	2	10%	1	3%	0	0%
Malvaceae testa	1	5%	0	0%	0	0%
Rubiaceae	1	5%	0	0%	0	0%
Schleriaceae	1	5%	0	0%	0	0%
Indet culm node	1	5%	0	0%	0	0%
Indet internode	1	5%	0	0%	0	0%
Indet pedestal	1	5%	1	3%	0	0%
Indet striated seed coat	1	5%	0	0%	0	0%
Indet small legume	0	0%	1	3%	0	0%
Modern seeds	20	100%	31	97%	20	100%
Charcoal	19	95%	32	100%	18	90%
Indeterminate	14	70%	26	81%	4	20%

Appendix 7.5: Ubiquity values for published archaeobotanical data in North Indian Prehistoric sites. Dates are taken directly from the published reports.

	Hulaskera I	Hulaskera II	Hulaskera All	Manjhi II	Manjhi III	Manjhi All	Narhan I	Narhan II	Narhan III
Dates	700-500BC	500-200BC	-	600-50BC	50BC-AD300	-	1000-800BC	800-600BC	600-200BC
No of samples	5	1	6	3	1	4	32	17	5
Pulses	20%	0%	17%	100%	100%	100%	78%	59%	20%
Small millets	20%	100%	33%	33%	100%	50%	31%	0%	20%
Barley	60%	100%	67%	100%	100%	100%	63%	47%	20%
Wheat	0%	0%	0%	100%	100%	100%	66%	0%	20%
Rice	40%	0%	33%	100%	100%	100%	75%	53%	20%
Fruits	0%	0%	0%	0%	100%	25%	3%	0%	20%
All weeds	20%	0%	17%	100%	100%	100%	69%	0%	20%

	Narhan IV	Narhan All	Malhar I	Malhar II	Malhar All	Senuwar IA	Senuwar IB	Senuwar II	Senuwar All
Dates	200BC-AD400	-	2150-1600BC	1600-800BC	-	2200-1950BC	1950-1300BC	1300-600BC	-
No of samples	1	55	14	26	40	52	54	40	146
Pulses	0%	65%	71%	77%	75%	35%	43%	58%	44%
Small millets	0%	20%	57%	23%	30%	37%	20%	15%	25%
Barley	0%	53%	43%	46%	45%	23%	17%	35%	24%
Wheat	0%	40%	29%	15%	20%	12%	20%	30%	20%
Rice	0%	62%	64%	69%	68%	60%	50%	53%	54%
Fruits	0%	4%	14%	15%	15%	15%	2%	10%	9%
All weeds	0%	42%	43%	62%	55%	10%	9%	40%	18%

Appendix 7.6: Raw data table for macro-botanical remains from Gopalpur.

	Sample Gopalpur	GPR-03A-1	GPR-03A-2	GPR-03A-3	GPR-03A-4	GPR-03A-5	GPR-03A-6	GPR-03A-7	GPR-03A-8	GPR-03A-9	GPR-03A-10	GPR-03A-11	GPR-03A-12	GPR-03A-13	GPR-03A-15
		BOTTOM													TOP
	Soil vol (L)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Sample vol (ml)	5	2	6	8	15	5	2	6	1	1	3	2	12	2
	Density of sample per litre (ml)	0.25	0.1	0.3	0.4	0.75	0.25	0.1	0.3	0.05	0.05	0.15	0.1	0.6	0.1
	Vigna sp. (whole)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	Vigna sp. (cotyledon)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U	Vigna sp. (frag)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	Vigna cf. radiata	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Macrotyloma uniflorum (whole)	0	8	8	0	0	1	1	0	0	0	0	0	0	0
E	*Macrotyloma uniflorum*(cotyledon)	0	19	11	0	0	1	1	0	0	0	0	0	0	0
S	Macrotyloma uniflorum (frag)	0	38	73	0	0	10	8	2	1	0	0	0	0	0
	Cajanus cajan (whole)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cajanus cajan (cotyledon)	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Cajanus cajan (frag)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cajanus/ Lablab?	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pulse frags	35	101	166	3	3	62	22	14	6	3	5	0	0	0
C	Bracharia ramosa (hulled) well pres	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	B.ramosa (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	Setaria verticilliata (hulled) well pres	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	S. verticillata (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A	Setaria sp.	0	1	0	0	0	1	3	0	0	0	0	0	0	0
L	Panicum sumatrense	0	0	0	1	0	0	0	2	0	0	0	0	0	0
S	Panicum sp.	0	0	0	0	0	11	0	1	0	0	0	0	0	0

Appendix 7.6 continued: Raw data table for macro-botanical remains from Gopalpur.

	Sample Gopalpur	GPR-03A-1	GPR-03A-2	GPR-03A-3	GPR-03A-4	GPR-03A-5	GPR-03A-6	GPR-03A-7	GPR-03A-8	GPR-03A-9	GPR-03A-10	GPR-03A-11	GPR-03A-12	GPR-03A-13	GPR-03A-15
	Paspalum sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Echinochloa sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0
&	Indeterminate small millets	0	0	0	0	0	14	0	18	0	3	1	0	2	0
	Hordeum vulgare	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	Triticum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	Oryza sp. (whole caryopsis)	0	0	0	1	1	0	0	2	0	0	0	0	0	0
A	Oryza sp. (caryopsis 1/2)	3	1	2	1	1	8	2	1	0	2	2	1	2	0
S	Oryza sp. (caryopsis 1/4)	0	0	3	3	2	22	15	25	4	4	17	4	8	0
S	Oryza sp. (glumes)	0	0	1	0	0	0	0	0	0	0	1	0	1	0
E	Oryza sp. (spikelet base)	0	0	0	0	0	2	0	0	0	0	0	0	0	0
S	Indet. Graminae (caryopsis)	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	Ziziphus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Celtis sp.	0	1	0	0	0	0	0	0	0	0	0	1	0	0
	Cyperaceae type	0	0	0	0	0	0	1	2	0	0	0	0	0	0
W	cf. Cyperus sp.	0	0	0	0	0	0	0	3	0	0	0	0	0	0
E	cf. Andropogonal sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0
E	Cenchrus sp. type	0	1	0	0	0	0	0	0	0	0	0	0	0	0
D	cf. Eragrostis sp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0
S	Ischaemum rugosum	0	0	0	0	0	1	0	1	0	1	6	0	0	0
	Large grass type 1	0	24	4	1	0	0	0	0	0	0	0	0	0	0
	Small grass	0	7	0	0	0	0	2	0	0	0	0	0	0	0
	Polygonaceae type	0	0	0	0	0	14	2	2	0	0	4	1	1	0

Appendix 7.6 continued: Raw data table for macro-botanical remains from Gopalpur.

Sample Gopalpur	GPR-03A-1	GPR-03A-2	GPR-03A-3	GPR-03A-4	GPR-03A-5	GPR-03A-6	GPR-03A-7	GPR-03A-8	GPR-03A-9	GPR-03A-10	GPR-03A-11	GPR-03A-12	GPR-03A-13	GPR-03A-15
Rubiaceae fruit fragment	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Indet frunicular cap	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Charcoal	xx	xxx	xx	xx	xx	xx	xx	xx	x	x	xx	xx	x	x
Shoots	0	Y	0	0	0	0	0	0	0	0	0	0	0	0
Indeterminate	9	33	45	6	9	76	27	52	7	5	9	6	6	4
Total fragments	47	239	313	16	18	226	84	126	18	21	45	13	20	4

Appendix 7.7: Raw data table for macro-botanical remains from Golbai Sasan.

	Sample Golbai Sasan	GBSN-03A-3	GBSN-03A-5	GBSN-03A-7A	GBSN-03A-7B	GBSN-03A-8	GBSN-03A-9	GBSN-03A-10	GBSN-03A-11	GBSN-03A-12	GBSN-03A-13A	GBSN-03A-13B	GBSN-03A-13C	GBSN-03A-13D	GBSN-03A-14A	GBSN-03A-14B
		TOP													BOTTOM	
	Soil vol (L)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Sample vol (ml)	0.07	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.03	0.03	0.03	0.02	0.06	0.04
	Density of sample per litre (ml)	3.5	0.9	0.4	0.5	0.5	0.85	0.9	1.05	2.4	1.65	1.65	1.35	1.05	3.05	2.2
	Vigna sp. (whole)	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0
P	Vigna sp. (cotyledon)	39	0	0	0	0	1	0	2	4	0	0	2	2	1	0
U	Vigna sp. (frag)	48	0	0	0	0	0	0	5	0	0	2	0	1	0	0
L	Vigna cf. radiata	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Macrotyloma (whole)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
E	Macrotyloma (cotyledon)	0	0	0	0	0	3	1	1	5	0	1	0	0	0	0
S	Macrotyloma (frag)	0	0	0	0	0	6	0	0	3	0	0	0	2	0	0
	Cajanus (whole)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Cajanus (cotyledon)	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
	Cajanus (frag)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cajanus/ Lablab?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pulse frags	111	9	0	4	6	25	29	23	25	12	16	18	12	9	7
C	Bracharia ramosa (hulled) well pres	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0
E	B.ramosa (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	Setaria verticilliata (hulled) well pres	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	S. verticillata (caryopsis)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A	Setaria sp.	0	0	0	0	0	1	1	1	1	1	0	0	0	1	0
L	Panicum sumatrense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Panicum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7.7 continued: Raw data table for macro-botanical remains from Golbai Sasan.

	Sample Golbai Sasan	GBSN-03A-3	GBSN-03A-5	GBSN-03A-7A	GBSN-03A-7B	GBSN-03A-8	GBSN-03A-9	GBSN-03A-10	GBSN-03A-11	GBSN-03A-12	GBSN-03A-13A	GBSN-03A-13B	GBSN-03A-13C	GBSN-03A-13D	GBSN-03A-14A	GBSN-03A-14B
	Paspalum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
&	Paspalum sp. cf. vaginatum	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Indeterminate small millet	0	0	1	0	0	5	0	3	1	4	0	0	0	0	2
G	Hordeum vulgare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	Triticum sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A	Oryza sp. (whole caryopsis)	1	0	0	0	1	5	0	3	1	1	0	0	3	2	2
S	Oryza sp. (caryopsis 1/2)	4	3	0	0	2	19	7	12	17	0	4	4	6	9	12
S	Oryza sp. (caryopsis 1/4)	13	15	5	6	4	80	23	25	29	7	13	5	10	12	29
E	Oryza sp. (glume)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	Oryza sp. (husk imprints frags)	0	0	0	0	1	3	2	0	1	0	0	1	0	1	0
	Indet. Graminae (caryopsis)	0	2	0	0	0	24	10	6	13	0	2	0	5	0	7
	Ziziphus sp.	0	0	0	0	0	1	2	6	0	0	0	0	0	0	0
	Fruit stone unidentified	0	0	0	0	0	54	4	0	4	1	1	1	6	0	16
	Ficus sp.?	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0
	Aizoceae Trianthamea type	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
W	Asteraceae type	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	Asteraceae cf. Eclipta type	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
E	Asteraceae Tridex type	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
D	Cyperaceae type	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
S	Euphorbia type	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Euphorbia type cf. Phyllanthus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Appendix 7.7 continued: Raw data table for macro-botanical remains from Golbai Sasan.

Sample Golbai Sasan	GBSN-03A- 3	GBSN-03A-5	GBSN-03A-7A	GBSN-03A-7B	GBSN-03A-8	GBSN-03A-9	GBSN-03A-10	GBSN-03A-11	GBSN-03A-12	GBSN-03A-13A	GBSN-03A-13B	GBSN-03A-13C	GBSN-03A-13D	GBSN-03A-14A	GBSN-03A-14B
Ischaemum rugosum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Small grass	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Malvaceae type	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Polygonaceae type	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Portulaca sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Rubiaceae cf. Oldenlandia mericarp	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
Rubiaceae fruit fragment	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Scrophulariaceae cf. Lindernia/Scropia type	0	0	0	0	0	1	2	0	0	0	0	0	0	0	1
Indet embryo	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Indet striate seed case	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Charcoal	xx	x	xx	x	x	xxx	xx	xx	xx	x	xx	x	xx	xxx	xxx
Indeterminate	47	10	5	3	12	36	18	8	13	23	25	16	36	25	25
Total fragments	272	39	12	13	27	285	103	95	122	49	65	48	85	65	105

Appendix 7.8: Raw data table for macro-botanical remains from Bajpur.

	Sample Bajpur	BJR-03A-1	BJR-03A-2	BJR-03A-3	BJR-03A-4
	Soil vol (L)	20	20	20	20
	Sample vol (ml)	40	40	40	40
	Density per litre sediment (ml)	2.00	2.00	2.00	2.00
	Vigna sp. (whole)	0	0	0	0
P	Vigna sp. (cotyledon)	0	0	0	0
U	Vigna sp. (frag)	0	0	0	0
L	Vigna cf. radiata	0	0	0	0
S	Macrotyloma (whole)	0	0	0	0
E	Macrotyloma (cotyledon)	0	0	0	0
S	Macrotyloma (frag)	0	0	0	0
	Lens culinaris (whole)	0	0	0	0
	Lens culinaris (cotyledon)	0	0	0	0
	Lens culinaris (frag)	0	0	0	0
	Lathyrus sativus	0	0	0	0
	Pisum sativum	0	0	0	0
	Cajanus (whole)	0	0	0	0
	Cajanus (cotyledon)	0	0	0	0
	Cajanus (frag)	0	0	0	0
	Cajanus/ Lablab?	0	0	0	0
	Pulse frags	0	0	0	0
C	Bracharia ramosa (hulled) well pres	0	0	0	0
E	B.ramosa (caryopsis)	0	0	0	0
R	Setaria verticilliata (hulled) well pres	0	0	0	0
E	S. verticillata (caryopsis)	0	0	0	0
A	Panicum sumatrense	0	0	0	0
L	Setaria sp.	0	0	0	0
S	Panicum sp.	0	0	0	0
&	Paspalum sp.	0	0	0	0
G	Echinochloa	0	0	0	0
R	Indetreminate small millet	0	0	0	1
A	Hordeum vulgare	0	0	0	0
S	Triticum sp.	0	0	0	0
S	Oryza sp. (whole caryopsis)	0	0	0	0
E	Oryza sp. (caryopsis frags)	0	0	0	0
S	Indet. Graminae (caryopsis)	0	0	0	0
	Ziziphus sp.	0	0	0	0

Appendix 7.8 continued: Raw data table for macro-botanical remains from Bajpur.

	Sample Bajpur	BJR-03A-1	BJR-03A-2	BJR-03A-3	BJR-03A-4
W	Weeds seeds	0	0	0	0
E	modern seeds	xx	xx	xx	xx
E	Charcoal	xx	xx	xx	xx
D	Shoots	0	0	0	0
S	Indeterminate	1	1	0	0
	Total fragments	1	1	0	1

Appendix 7.9: Raw data table for macro-botanical remains from Malakhoja.

	Sample Malakhoja	MKA-03A-1	MKA-03A-2	MKA-03A-3	MKA-03A-4	MKA-03A-5	MKA-03A-6	MKA-03A-7	MKA-03A-8	MKA-03A-9	MKA-03A-10
	Soil vol (L)	20	20	20	20	20	20	20	20	20	20
	Sample vol (ml)	75	152	30	100	30	15	15	30	20	15
	Density per litre sediment (ml)	3.75	7.6	1.5	5	1.5	0.75	0.75	1.5	1	0.75
	Vigna sp. (whole)	0	0	0	0	0	0	0	0	0	0
P	Vigna sp. (cotyledon)	0	0	0	0	0	0	0	0	0	0
U	Vigna sp. (frag)	0	0	0	0	0	0	0	0	0	0
L	Vigna cf. radiata	0	0	0	0	0	0	0	0	0	0
S	Macrotyloma (whole)	0	0	0	0	0	0	0	0	0	0
E	Macrotyloma (cotyledon)	0	0	0	0	0	0	0	0	0	0
S	Macrotyloma (frag)	0	0	0	0	0	0	0	0	0	0
	Lens culinaris (whole)	0	0	0	0	0	0	0	0	0	0
	Lens culinaris (cotyledon)	0	0	0	0	0	0	0	0	0	0
	Lens culinaris (frag)	0	0	0	0	0	0	0	0	0	0
	Lathyrus sativus	0	0	0	0	0	0	0	0	0	0
	Pisum sativum	0	0	0	0	0	0	0	0	0	0
	Cajanus (whole)	0	0	0	0	0	0	0	0	0	0
	Cajanus (cotyledon)	0	0	0	0	0	0	0	0	0	0
	Cajanus (frag)	0	0	0	0	0	0	0	0	0	0
	Cajanus/ Lablab?	0	0	0	0	0	0	0	0	0	0
	Pulse frags	0	0	0	0	0	0	0	0	0	0
C	Bracharia ramosa (hulled) well pres	0	0	0	0	0	0	0	0	0	0
E	B.ramosa (caryopsis)	0	0	0	0	0	0	0	0	0	0
R	Setaria verticilliata (hulled) well pres	0	0	0	0	0	0	0	0	0	0
E	S. verticillata (caryopsis)	0	0	0	0	0	0	0	0	0	0
A	Panicum sumatrense	0	0	0	0	0	0	0	0	0	0
L	Setaria sp.	0	0	0	0	0	0	0	0	0	0
S	Panicum sp.	0	0	0	0	0	0	0	0	0	0
&	Paspalum sp.	0	0	0	0	0	0	0	0	0	0
	Echinochloa	0	0	0	0	0	0	0	0	0	0
G	Other millets	0	0	0	0	0	0	0	0	0	0
R	Hordeum vulgare	0	0	0	0	0	0	0	0	0	0
A	Triticum sp.	0	0	0	0	0	0	0	0	0	0
S	Oryza sp. (whole caryopsis)	0	0	0	0	0	0	0	0	0	0
S	Oryza sp. (caryopsis frags)	3	0	0	0	0	0	0	0	0	0
E	Oryza sp. (husk frag)	1	0	0	0	0	0	0	0	0	0
S	Indet. Graminae (caryopsis)	0	0	0	0	0	0	0	0	0	0
	Ziziphus sp.	0	0	0	0	0	0	0	0	0	0

Appendix 7.9 continued: Raw data table for macro-botanical remains from Malakhoja.

	Sample Malakhoja	MKA-03A-1	MKA-03A-2	MKA-03A-3	MKA-03A-4	MKA-03A-5	MKA-03A-6	MKA-03A-7	MKA-03A-8	MKA-03A-9	MKA-03A-10
W	Weeds seeds	0	0	0	0	0	0	0	0	0	0
E	modern seeds	x	x	x	x	x	x	x	x	x	x
E	Charcoal	x	x	1 x	1 x	1 x	1 x	1 x	0	1 x	1 x
D	Shoots	0	0	0	0	0	0	0	0	0	0
S	Indeterminate	1	0	0	0	0	0	0	0	2	0
	Total fragments	5	0	0	0	0	0	0	0	2	0

Appendix 7.10: Raw data table for macro-botanical remains from Banabasa.

	Sample Banabasa	BNA-03A-1	BNA-03A-2	BNA-03A-3
	Soil vol (L)	20	20	20
	Sample vol (ml)	75	80	22
	Density per litre sediment (ml)	3.75	4	1.1
	Vigna sp. (whole)	0	0	0
P	Vigna sp. (cotyledon)	0	0	0
U	Vigna sp. (frag)	0	0	0
L	Vigna cf. radiata	0	0	0
S	Macrotyloma (whole)	0	0	0
E	Macrotyloma (cotyledon)	0	0	0
S	Macrotyloma (frag)	0	0	0
	Lens culinaris (whole)	0	0	0
	Lens culinaris (cotyledon)	0	0	0
	Lens culinaris (frag)	0	0	0
	Lathyrus sativus	0	0	0
	Pisum sativum	0	0	0
	Cajanus (whole)	0	0	0
	Cajanus (cotyledon)	0	0	0
	Cajanus (frag)	0	0	0
	Cajanus/ Lablab?	0	0	0
	Pulse frags	0	0	0
C	Bracharia ramosa (hulled) well pres	0	0	0
E	B.ramosa (caryopsis)	0	0	0
R	Setaria verticilliata (hulled) well pres	0	0	0
E	S. verticillata (caryopsis)	0	0	0
A	Panicum sumatrense	0	0	0
L	Setaria sp.	0	0	0
S	Panicum sp.	0	0	0
&	Paspalum sp.	0	0	0
G	Echinochloa	0	0	0
R	Other millets	0	0	0
A	Hordeum vulgare	0	0	0
S	Triticum sp.	0	0	0
S	Oryza sp. (whole caryopsis)	0	0	0
E	Oryza sp. (caryopsis frags)	0	0	0
S	Indet. Graminae (caryopsis)	0	0	0
	Ziziphus sp.	0	0	0

Appendix 7.10 continued: Raw data table for macro-botanical remains from Banabasa.

	Sample Banabasa	BNA-03A-1	BNA-03A-2	BNA-03A-3
W	Weeds seeds	0	0	0
E	modern seeds	xx	xx	x
E	Charcoal	x	x	x
D	Shoots	0	0	0
S	Unknowns	0	0	0
	Total fragments	0	0	0

Appendix 7.11: Results table for phytolith absolute densities (number per gram of sediment) from Koldihwa.

Single-cell	KDW-01-1	KDW-01-2	KDW-01-3	KDW-01-4	KDW-01-5	KDW-01-6	KDW-01-7	KDW-01-8	KDW-01-9	KDW-01-10	KDW-01-11
Long (Smooth)	52926	120157	49351	17106	11909	25877	53262	42974	11131	9463	3341
Long (Sinuate)	6615	7152	2313	2534	1082	2322	5393	3657	706	249	57
Long (Rods)	2940	5721	0	422	0	331	0	0	0	249	57
Long (Dendritic)	30873	55787	28531	8236	6676	6303	14832	15086	3533	1245	485
Papillae	2205	0	771	633	0	0	0	0	0	0	28
Hairs	735	1430	2313	422	0	0	674	3200	353	124	57
Trichomes	7350	5721	12337	844	3067	1658	6067	7772	530	373	314
Bulliform	47780	38622	22362	18795	13894	28863	33036	19658	12014	6973	2256
Ovals	735	1430	0	422	361	332	1348	0	707	249	57
Keystone	18377	20026	16194	15628	16782	42465	25620	22859	21202	11830	4712
Crenates	5146	4291	0	422	180	332	674	457	177	0	28
Bilobes	131581	141614	60148	13938	11910	9953	28991	34746	3357	1868	456
Crosses	15437	11444	1542	1056	541	3649	2697	1829	530	374	456
Rondels	45575	57218	19278	7814	7579	8626	16181	10972	3534	2740	342
Saddles	45575	17165	17736	6547	8301	18579	8091	22402	4240	2989	685
Cones	735	0	771	422	722	1659	0	0	0	0	0
Flat Tower	2205	4291	3856	1478	722	664	0	0	353	0	28
Horned Tower	1470	4291	2313	422	180	0	674	914	0	0	0
Rice bulliform	2940	1430	0	634	0	0	2023	457	530	0	29
Phragmites bulliform	0	0	0	0	0	0	0	0	0	0	0
Double-peaked glume cell	6616	2861	4627	634	0	0	1348	2286	177	125	0
Rice bilobe	1470	2861	1542	422	361	664	674	914	530	374	29
Rugulose Spheroid	0	0	1542	211	0	332	0	914	530	623	86
Smooth Spheroid	0	4291	0	0	541	0	1348	1372	0	249	0
Elongate	6616	7152	3856	2323	1805	2986	6742	3657	353	249	29
Tracheids	1470	15735	771	1056	541	995	2023	4115	177	249	29
Two-Tiered	0	0	0	1689	0	0	0	0	0	0	0

Appendix 7.11 continued: Results table for phytolith absolute densities (number per gram of sediment) from Koldihwa.

Phytolith morphotype	KDW-01-1	KDW-01-2	KDW-01-3	KDW-01-4	KDW-01-5	KDW-01-6	KDW-01-7	KDW-01-8	KDW-01-9	KDW-01-10	KDW-01-11
Blocks	0	0	0	0	0	0	0	0	0	0	0
Platey	735	4291	2313	211	0	0	674	0	0	249	29
Sheet	11026	14304	8482	3590	2165	3649	8765	1372	883	374	143
Scalloped	0	0	0	0	0	0	0	0	0	0	0
Single Jigsaw puzzle	1470	2861	0	211	0	0	674	0	0	0	0
Total single cells:	**450608**	**552152**	**262953**	**108127**	**89323**	**160241**	**221816**	**201616**	**65550**	**41218**	**13737**
Multi-cell											
Leaf/Stem	16172	20026	12338	2957	1083	369	14833	6629	707	311	86
Unident Husk	22788	54357	14266	3907	619	332	5731	2743	309	156	36
Cereal husk	19112	24318	19664	950	464	258	1686	1143	88	0	7
Millet husk	4411	2861	1542	0	52	37	337	0	0	0	0
Phragmites Stem	0	0	0	106	0	0	337	0	0	0	0
Rice husk	23523	40053	19664	1162	876	258	7079	10287	707	249	86
Rice leaf/stem	0	0	0	0	103	0	337	229	44	0	0
Cyperaceae	2940	5722	0	1162	2217	2544	4719	6629	3092	2335	507
Square-cell leaf/stem	1470	1430	1928	422	52	37	337	229	44	0	0
Polyhedral hair base	735	0	0	0	0	0	0	0	0	0	7
Mesophyll type	0	0	0	0	0	0	0	0	0	0	0
Diatoms	0	0	0	0	0	0	0	0	0	0	0
Silica aggregate	0	0	386	0	103	0	1011	1143	0	156	21
Total multi-cells:	**91151**	**148766**	**69787**	**10665**	**5568**	**3834**	**36407**	**29031**	**4991**	**3207**	**750**
Total phytolith:	**541759**	**700919**	**332740**	**118792**	**94891**	**164074**	**258223**	**230647**	**70542**	**44424**	**14487**

Appendix 7.12: Results table for phytolith absolute densities (number per gram of sediment) from Mahagara.

Single-cell	MGR-02-1	MGR-02-2	MGR-02-3	MGR-02-4	MGR-02-5	MGR-02-6	MGR-02-7	MGR-02-8	MGR-02-9	MGR-02-10
Long (Smooth)	77	610	891	994	1292	883	431	416	544	502
Long (Sinuate)	47	528	429	389	848	499	363	96	40	51
Long (Rods)	33	82	0	0	0	38	0	0	0	0
Long (Dendritic)	47	1023	1683	1599	1737	1228	975	58	62	77
Papillae	0	0	0	0	0	38	0	0	0	0
Hairs	3	16	132	0	0	115	0	0	0	0
Trichomes	0	0	0	0	0	38	45	13	6	0
Bulliform	33	82	198	65	969	115	839	64	96	128
Ovals	3	33	33	0	40	0	23	13	0	0
Keystone	150	280	1320	1988	3635	3185	1973	499	527	400
Crenates	17	66	165	65	242	77	113	6	6	9
Bilobes	153	544	2706	1318	3069	2302	1384	122	40	43
Crosses	50	115	759	281	969	384	431	32	28	17
Rondels	20	49	66	130	283	307	204	51	34	26
Saddles	333	1023	1089	562	2342	2187	1270	397	221	51
Cones	7	16	33	0	0	38	0	6	11	0
Flat Tower	33	49	0	0	0	77	91	19	17	0
Horned Tower	0	0	0	0	0	0	0	26	6	0
Rice bulliform	10	0	66	86	40	77	113	0	0	0
Phragmites bulliform	0	0	0	22	0	0	0	0	0	0
Double-peaked glume cell	17	0	33	65	40	153	68	0	0	0
Rice bilobe	13	0	66	108	40	77	136	0	0	0
Rugulose Spheroid	27	33	33	0	40	38	45	26	45	17
Smooth Spheroid	3	16	0	65	162	153	45	6	11	0
Elongate	0	82	132	108	81	230	23	13	28	26
Tracheids	0	49	396	259	0	0	0	0	0	9
Two-Tiered	0	0	0	0	0	38	0	0	0	0
Blocks	0	0	0	43	121	0	23	0	0	9
Platey	7	99	0	0	0	38	0	0	0	0
Sheet	0	214	165	22	81	77	91	32	23	51
Single Polyhedron	0	0	0	0	0	0	0	0	0	0
Scalloped	0	0	99	43	0	0	0	0	0	0
Single Jigsaw puzzle	0	0	0	0	0	0	0	0	0	0
Total single cells:	**1082**	**5015**	**10493**	**8210**	**16033**	**12394**	**8687**	**1895**	**1746**	**1413**

Appendix 7.12 continued: Results table for phytolith absolute densities (number per gram of sediment) from Mahagara.

Multi-cell	MGR-02-1	MGR-02-2	MGR-02-3	MGR-02-4	MGR-02-5	MGR-02-6	MGR-02-7	MGR-02-8	MGR-02-9	MGR-02-10
Leaf/Stem	12	82	434	278	263	205	156	3	8	0
Unident Husk	12	231	1376	649	808	1049	439	15	8	9
Millet husk	2	7	0	0	80	26	28	0	0	0
Phragmites Stem	0	0	57	19	40	0	0	0	0	0
Rice husk	2	27	283	111	40	102	99	0	0	0
Cyperaceae	0	0	0	37	61	26	57	0	3	0
Square-cell leaf/stem	0	0	0	0	0	0	0	0	0	0
Mesophyll type	0	0	0	0	0	0	0	0	0	0
Diatoms	30	163	57	93	101	281	298	252	169	145
Total multi-cells:	**59**	**509**	**2206**	**1185**	**1393**	**1688**	**1077**	**270**	**189**	**153**
Total phytoliths:	**1141**	**5524**	**12700**	**9395**	**17427**	**14082**	**9764**	**2165**	**1935**	**1566**

Appendix 7.13: Results table for phytolith absolute density (number per gram of sediment) from Chopani Mando.

Single-cell	CPM-01-1	CPM-01-3	CPM-01-5	CPM-01-7	CPM-01-9
Long (Smooth)	5795	10057	2119	4809	905
Long (Sinuate)	216	532	110	174	52
Long (Rods)	0	0	0	0	0
Long (Dendritic)	36	133	0	21	17
Papillae	0	0	0	0	0
Hairs	0	0	0	21	0
Trichomes	431	466	124	217	74
Bulliform	2267	2730	817	1109	158
Ovals	36	0	55	0	4
Keystone	2447	2863	568	805	263
Crenates	0	0	0	0	0
Bilobes	36	133	13	108	30
Crosses	0	0	0	0	0
Rondels	0.00	333	27	87	21
Saddles	216	0.00	55	43	39
Cones	0	0	0	0	0
Flat Tower	0	0	0	0	0
Horned Tower	0	0	0	0	0
Rice bulliform	0	0	0	0	0
Phragmites bulliform	0	0	0	0	0
Double-peaked glume cell	0	0	0	0	0
Rice bilobe	0	0	0	0	0
Rugulose Spheroid	252	1132	235	500	70
Smooth Spheroid	0	133	0	21	17
Elongate	36	333	41	130	17
Tracheids	0	0	0	0	0
Blocks	0	0	0	0	0
Platey	0	66	0	0	17
Sheet	216	266	13	652	13
Scalloped	36	0	0	0	0
Single Jigsaw puzzle	0	0	0	0	0
Total single cells:	**12024**	**19182**	**4184**	**8706**	**1706**

Appendix 7.13 continued: Results table for phytolith absolute density (number per gram of sediment) from Chopani-Mando.

Multi-cell	CPM-01-1	CPM-01-3	CPM-01-5	CPM-01-7	CPM-01-9
Leaf/Stem	0	3	1	1	0
Unident Husk	2	0	0	0	0
Cereal husk	0	0	0	0	0
Millet husk	0	0	0	0	0
Rice husk	0	0	0	0	0
Rice leaf/stem	0	0	0	0	0
Cyperaceae	2	0	1	0	0
Square-cell leaf/stem	0	0	1	0	0
Mesophyll type	0	0	0	0	0
Diatoms	3	8	2	1	6
Silica aggregate	5	8	5	1	0
Total multi-cells:	**11**	**19**	**9**	**3**	**6**
Total phytoliths:	**12034**	**19201**	**4193**	**8708**	**1711**

Appendix 7.14: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Chopani-Mando.

Sample number	1	3	5	7	9
Long (Smooth)	48.2%	52.4%	50.7%	55.3%	53.1%
Long (Sinuate)	1.8%	2.8%	2.6%	2.0%	3.1%
Long (Rods)	0.0%	0.0%	0.0%	0.0%	0.0%
Long (Dendritic)	0.3%	0.7%	0.0%	0.3%	1.0%
Papillae	0.0%	0.0%	0.0%	0.0%	0.0%
Hairs	0.0%	0.0%	0.0%	0.3%	0.0%
Trichomes	3.6%	2.4%	3.0%	2.5%	4.4%
Bulliform	18.9%	14.2%	19.5%	12.8%	9.3%
Ovals	0.3%	0.0%	1.3%	0.0%	0.3%
Keystone	20.4%	14.9%	13.6%	9.3%	15.5%
Crenates	0.0%	0.0%	0.0%	0.0%	0.0%
Bilobes	0.3%	0.7%	0.3%	1.3%	1.8%
Crosses	0.0%	0.0%	0.0%	0.0%	0.0%
Rondels	0.0%	1.7%	0.7%	1.0%	1.3%
Saddles	1.8%	0.0%	1.3%	0.5%	2.3%
Cones	0.0%	0.0%	0.0%	0.0%	0.0%
Flat Tower	0.0%	0.0%	0.0%	0.0%	0.0%
Horned Tower	0.0%	0.0%	0.0%	0.0%	0.0%
Rice bulliform	0.0%	0.0%	0.0%	0.0%	0.0%
Phragmites bulliform	0.0%	0.0%	0.0%	0.0%	0.0%
Double-peaked glume cell	0.0%	0.0%	0.0%	0.0%	0.0%
Rice bilobe	0.0%	0.0%	0.0%	0.0%	0.0%
Rugulose Spheroid	2.1%	5.9%	5.6%	5.8%	4.1%
Smooth Spheroid	0.0%	0.7%	0.0%	0.3%	1.0%
Elongate	0.3%	1.7%	1.0%	1.5%	1.0%
Tracheids	0.0%	0.0%	0.0%	0.0%	0.0%
Blocks	0.0%	0.0%	0.0%	0.0%	0.0%
Platey	0.0%	0.3%	0.0%	0.0%	1.0%
Sheet	1.8%	1.4%	0.3%	7.5%	0.8%
Scalloped	0.3%	0.0%	0.0%	0.0%	0.0%
Single Jigsaw puzzle	0.0%	0.0%	0.0%	0.0%	0.0%

Appendix 7.14 continued: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Chopani-Mando.

Sample number	1	3	5	7	9
Leaf/Stem	0.0%	14.3%	6.3%	33.3%	0.0%
Unident Husk	14.3%	0.0%	0.0%	0.0%	0.0%
Cereal husk	0.0%	0.0%	0.0%	0.0%	0.0%
Millet husk	0.0%	0.0%	0.0%	0.0%	0.0%
Rice husk:	0.0%	0.0%	0.0%	0.0%	0.0%
Rice leaf/stem	0.0%	0.0%	0.0%	0.0%	0.0%
Cyperaceae	14.3%	0.0%	6.3%	0.0%	0.0%
Square-cell leaf/stem	0.0%	0.0%	12.5%	0.0%	0.0%
Mesophyll type	0.0%	0.0%	0.0%	0.0%	0.0%
Diatoms	28.6%	42.9%	18.8%	33.3%	100.0%
Silica aggregate	42.9%	42.9%	56.3%	33.3%	0.0%

Appendix 7.15: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Koldihwa.

Sample number	1	2	3	4	5	6	7	8	9	10	11
Long (Smooth)	11.7%	21.8%	18.8%	15.8%	13.3%	16.1%	24.0%	21.3%	17.0%	23.0%	24.3%
Long (Sinuate)	1.5%	1.3%	0.9%	2.3%	1.2%	1.4%	2.4%	1.8%	1.1%	0.6%	0.4%
Long (Rods)	0.7%	1.0%	0.0%	0.4%	0.0%	0.2%	0.0%	0.0%	0.0%	0.6%	0.4%
Long (Dendritic)	6.9%	10.1%	10.9%	7.6%	7.5%	3.9%	6.7%	7.5%	5.4%	3.0%	3.5%
Papillae	0.5%	0.0%	0.3%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
Hairs	0.2%	0.3%	0.9%	0.4%	0.0%	0.0%	0.3%	1.6%	0.5%	0.3%	0.4%
Trichomes	1.6%	1.0%	4.7%	0.8%	3.4%	1.0%	2.7%	3.9%	0.8%	0.9%	2.3%
Bulliform	10.6%	7.0%	8.5%	17.4%	15.6%	18.0%	14.9%	9.8%	18.3%	16.9%	16.4%
Ovals	0.2%	0.3%	0.0%	0.4%	0.4%	0.2%	0.6%	0.0%	1.1%	0.6%	0.4%
Keystone	4.1%	3.6%	6.2%	14.5%	18.8%	26.5%	11.6%	11.3%	32.3%	28.7%	34.3%
Crenates	1.1%	0.8%	0.0%	0.4%	0.2%	0.2%	0.3%	0.2%	0.3%	0.0%	0.2%
Bilobes	29.2%	25.6%	22.9%	12.9%	13.3%	6.2%	13.1%	17.2%	5.1%	4.5%	3.3%
Crosses	3.4%	2.1%	0.6%	1.0%	0.6%	2.3%	1.2%	0.9%	0.8%	0.9%	3.3%
Rondels	10.1%	10.4%	7.3%	7.2%	8.5%	5.4%	7.3%	5.4%	5.4%	6.6%	2.5%
Saddles	10.1%	3.1%	6.7%	6.1%	9.3%	11.6%	3.6%	11.1%	6.5%	7.3%	5.0%
Cones	0.2%	0.0%	0.3%	0.4%	0.8%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Flat Tower	0.5%	0.8%	1.5%	1.4%	0.8%	0.4%	0.0%	0.0%	0.5%	0.0%	0.2%
Horned Tower	0.3%	0.8%	0.9%	0.4%	0.2%	0.0%	0.3%	0.5%	0.0%	0.0%	0.0%
Rice bulliform	0.7%	0.3%	0.0%	0.6%	0.0%	0.0%	0.9%	0.2%	0.8%	0.0%	0.2%
Phragmites bulliform	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Double-peaked glume cell	1.5%	0.5%	1.8%	0.6%	0.0%	0.0%	0.6%	1.1%	0.3%	0.3%	0.0%
Rice bilobe	0.3%	0.5%	0.6%	0.4%	0.4%	0.4%	0.3%	0.5%	0.8%	0.9%	0.2%
Rugulose Spheroid	0.0%	0.0%	0.6%	0.2%	0.0%	0.2%	0.0%	0.5%	0.8%	1.5%	0.6%
Smooth Spheroid	0.0%	0.8%	0.0%	0.0%	0.6%	0.0%	0.6%	0.7%	0.0%	0.6%	0.0%
Elongate	1.5%	1.3%	1.5%	2.1%	2.0%	1.9%	3.0%	1.8%	0.5%	0.6%	0.2%
Tracheids	0.3%	2.8%	0.3%	1.0%	0.6%	0.6%	0.9%	2.0%	0.3%	0.6%	0.2%
Two-Tiered	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Blocks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Platey	0.2%	0.8%	0.9%	0.2%	0.0%	0.0%	0.3%	0.0%	0.0%	0.6%	0.2%
Sheet	2.4%	2.6%	3.2%	3.3%	2.4%	2.3%	4.0%	0.7%	1.3%	0.9%	1.0%
Scalloped	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Single Jigsaw puzzle	0.3%	0.5%	0.0%	0.2%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%

Appendix 7.15 continued: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Koldihwa.

Sample number	1	2	3	4	5	6	7	8	9	10	11
Leaf/Stem	17.7%	13.5%	17.7%	27.7%	19.4%	9.6%	40.7%	22.8%	14.2%	9.7%	11.4%
Unident Husk	25.0%	36.5%	20.4%	36.6%	11.1%	8.7%	15.7%	9.4%	6.2%	4.9%	4.8%
Cereal husk	21.0%	16.3%	28.2%	8.9%	8.3%	6.7%	4.6%	3.9%	1.8%	0.0%	1.0%
Millet husk	4.8%	1.9%	2.2%	0.0%	0.9%	1.0%	0.9%	0.0%	0.0%	0.0%	0.0%
Phragmites Stem	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%
Rice husk	25.8%	26.9%	28.2%	10.9%	15.7%	6.7%	19.4%	35.4%	14.2%	7.8%	11.4%
Rice leaf/stem	0.0%	0.0%	0.0%	0.0%	1.9%	0.0%	0.9%	0.8%	0.9%	0.0%	0.0%
Cyperaceae	3.2%	3.8%	0.0%	10.9%	39.8%	66.3%	13.0%	22.8%	61.9%	72.8%	67.6%
Square-cell leaf/stem	1.6%	1.0%	2.8%	4.0%	0.9%	1.0%	0.9%	0.8%	0.9%	0.0%	0.0%
Polyhedral hair base	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%
Mesophyll type	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Diatoms	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Silica aggregate	0.0%	0.0%	0.6%	0.0%	1.9%	0.0%	2.8%	3.9%	0.0%	4.9%	2.9%

Appendix 7.16: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Mahagara.

Sample number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Long (Smooth)	7.1%	12.2%	8.5%	12.1%	8.1%	7.1%	5.0%	22.0%	31.2%	35.5%
Long (Sinuate)	4.3%	10.5%	4.1%	4.7%	5.3%	4.0%	4.2%	5.1%	2.3%	3.6%
Long (Rods)	3.1%	1.6%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
Long (Dendritic)	4.3%	20.4%	16.0%	19.5%	10.8%	9.9%	11.2%	3.0%	3.6%	5.4%
Papillae	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
Hairs	0.3%	0.3%	1.3%	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%
Trichomes	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.5%	0.7%	0.3%	0.0%
Bulliform	3.1%	1.6%	1.9%	0.8%	6.0%	0.9%	9.7%	3.4%	5.5%	9.0%
Ovals	0.3%	0.7%	0.3%	0.0%	0.3%	0.0%	0.3%	0.7%	0.0%	0.0%
Keystone	13.8%	5.6%	12.6%	24.2%	22.7%	25.7%	22.7%	26.4%	30.2%	28.3%
Crenates	1.5%	1.3%	1.6%	0.8%	1.5%	0.6%	1.3%	0.3%	0.3%	0.6%
Bilobes	14.2%	10.9%	25.8%	16.1%	19.1%	18.6%	15.9%	6.4%	2.3%	3.0%
Crosses	4.6%	2.3%	7.2%	3.4%	6.0%	3.1%	5.0%	1.7%	1.6%	1.2%
Rondels	1.8%	1.0%	0.6%	1.6%	1.8%	2.5%	2.3%	2.7%	1.9%	1.8%
Saddles	30.8%	20.4%	10.4%	6.8%	14.6%	17.6%	14.6%	20.9%	12.7%	3.6%
Cones	0.6%	0.3%	0.3%	0.0%	0.0%	0.3%	0.0%	0.3%	0.6%	0.0%
Flat Tower	3.1%	1.0%	0.0%	0.0%	0.0%	0.6%	1.0%	1.0%	1.0%	0.0%
Horned Tower	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.3%	0.0%
Rice bulliform	0.9%	0.0%	0.6%	1.1%	0.3%	0.6%	1.3%	0.0%	0.0%	0.0%
Phragmites bulliform	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Double-peaked glume cell	1.5%	0.0%	0.3%	0.8%	0.3%	1.2%	0.8%	0.0%	0.0%	0.0%
Rice bilobe	1.2%	0.0%	0.6%	1.3%	0.3%	0.6%	1.6%	0.0%	0.0%	0.0%
Rugulose Spheroid	2.5%	0.7%	0.3%	0.0%	0.3%	0.3%	0.5%	1.4%	2.6%	1.2%
Smooth Spheroid	0.3%	0.3%	0.0%	0.8%	1.0%	1.2%	0.5%	0.3%	0.6%	0.0%
Elongate	0.0%	1.6%	1.3%	1.3%	0.5%	1.9%	0.3%	0.7%	1.6%	1.8%
Tracheids	0.0%	1.0%	3.8%	3.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
Two-Tiered	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
Blocks	0.0%	0.0%	0.0%	0.5%	0.8%	0.0%	0.3%	0.0%	0.0%	0.6%
Platey	0.6%	2.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
Sheet	0.0%	4.3%	1.6%	0.3%	0.5%	0.6%	1.0%	1.7%	1.3%	3.6%
Scalloped	0.0%	0.0%	0.9%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Single Jigsaw puzzle	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Appendix 7.16 continued: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Mahagara.

Sample number	1	2	3	4	5	6	7	8	9	10
Leaf/Stem	20.7%	16.0%	19.7%	23.4%	18.8%	12.1%	14.5%	1.1%	4.4%	0.0%
Unident Husk	20.7%	45.3%	62.4%	54.7%	58.0%	62.1%	40.8%	5.6%	4.4%	5.6%
Millet husk	3.4%	1.3%	0.0%	0.0%	5.8%	1.5%	2.6%	0.0%	0.0%	0.0%
Phragmites Stem	0.0%	0.0%	2.6%	1.6%	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%
Rice husk	3.4%	5.3%	12.8%	9.4%	2.9%	6.1%	9.2%	0.0%	0.0%	0.0%
Cyperaceae	0.0%	0.0%	0.0%	3.1%	4.3%	1.5%	5.3%	0.0%	1.5%	0.0%
Square-cell leaf/stem	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mesophyll type	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Diatoms	51.7%	32.0%	2.6%	7.8%	7.2%	16.7%	27.6%	93.3%	89.7%	94.4%

Appendix 7.17: Results table for phytolith absolute density (number per gram of sediment) from Bajpur.

Single-cell	BJR-03-0	BJR-03-1	BJR-03-2	BJR-03-3	BJR-03-4
Long (Smooth)	8789	15482	13291	9177	42384
Long (Sinuate)	1143	481	652	1278	4645
Long (Rods)	0	0	0	0	0
Long (Dendritic)	352	288	163	232	290
Papillae	88	0	0	0	290
Hairs	0	0	82	232	581
Trichomes	1143	1250	897	929	3193
Bulliform	12217	6250	6034	6854	25256
Ovals	176	481	245	349	0
Keystone	16172	18655	18999	19516	76349
Crenates	0	0	0	0	0
Bilobes	879	288	163	232	290
Crosses	88	0	0	0	0
Rondels	0	192	245	697	581
Saddles	879	1346	1305	1626	5225
Cones	176	0	0	116	290
Flat Tower	0	0	0	116	0
Horned Tower	88	0	82	0	0
Rice bulliform	615	96	82	0	0
Phragmites bulliform	88	0	0	0	0
Double-peaked glume cell	0	0	0	0	0
Rice bilobe	88	0	0	0	0
Rugulose Spheroid	264	96	489	465	581
Smooth Spheroid	176	192	163	0	290
Elongate	264	192	326	349	3193
Tracheids	264	0	0	0	0
Blocks	88	481	163	0	871
Platey	176	0	0	0	581
Sheet	0	0	163	116	2322
Scalloped	0	96	0	0	871
Single Jigsaw puzzle	88	0	0	0	0
Total single cells:	**44298**	**45868**	**43544**	**42286**	**168085**

Appendix 7.17 continued: Results table for phytolith absolute density (number per gram of sediment) from Bajpur.

Multi-cell	BJR-03-0	BJR-03-1	BJR-03-2	BJR-03-3	BJR-03-4
Leaf/Stem	15	0	10	0	0
Unident Husk	4	0	0	0	0
Cereal husk	0	0	0	0	0
Millet husk	0	0	0	0	0
Rice husk	7	0	0	0	0
Rice leaf/stem	0	0	0	0	0
Cyperaceae	15	0	0	0	0
Square-cell leaf/stem	0	0	0	0	0
Mesophyll type	0	0	0	0	0
Diatoms	0	0	0	0	0
Silica aggregate	88	112	65	31	73
Indet multi-cell	0	0	0	2	0
Total multi-cells:	**128**	**112**	**75**	**34**	**73**
Total phytoliths:	**44426**	**45980**	**43618**	**42319**	**168157**

Appendix 7.18: Results table for phytolith absolute density (number per gram of sediment) from Malakhoja.

Single-cell	**1**	**4**	**7**	**9**
Long (Smooth)	13970	18653	9514	4090
Long (Sinuate)	916	1554	423	422
Long (Rods)	0	0	0	0
Long (Dendritic)	229	666	282	42
Papillae	115	0	0	0
Hairs	0	0	0	0
Trichomes	802	1554	423	295
Bulliform	7100	9326	3806	1855
Ovals	229	0	0	42
Keystone	16032	34863	12474	4596
Crenates	0	0	0	0
Bilobes	229	222	0	42
Crosses	0	0	0	0
Rondels	229	888	775	0
Saddles	1145	4885	634	211
Cones	0	0	0	0
Flat Tower	0	0	0	0
Horned Tower	0	0	0	0
Rice bulliform	0	0	0	0
Phragmites bulliform	0	0	0	0
Double-peaked glume cell	0	0	0	0
Rice bilobe	0	0	0	0
Rugulose Spheroid	0	222	0	0
Smooth Spheroid	0	0	0	0
Elongate	344	666	141	169
Tracheids	0	0	0	0
Blocks	344	3997	634	506
Platey	0	0	0	0
Sheet	229	1554	141	253
Scalloped	115	222	0	42
Single Jigsaw puzzle	344	0	0	0
Total single cells:	**42369**	**79274**	**29247**	**12565**

Appendix 7.18 continued: Results table for phytolith absolute density (number per gram of sediment) from Malakhoja.

Multi-cell	**1**	**4**	**7**	**9**
Leaf/Stem	7	5	0	0
Unident Husk	0	0	0	3
Cereal husk	0	0	0	0
Millet husk:	0	0	0	0
Rice husk:	0	0	0	0
Rice leaf/stem	0	0	0	0
Cyperaceae	0	0	0	3
Square-cell leaf/stem	0	0	0	0
Mesophyll type	0	0	0	0
Diatoms	0	0	0	0
Silica aggregate	21	94	38	84
Total multi-cells:	**29**	**99**	**38**	**90**
Total phytoliths	**42398**	**79373**	**29285**	**12655**

Appendix 7.19: Results table for phytolith absolute density (number per gram of sediment) from Gopalpur.

Single-cell	GPR-03A-1	GPR-03A-2	GPR-03A-3	GPR-03A-4	GPR-03A-5	GPR-03A-6	GPR-03A-7	GPR-03A-8	GPR-03A-9	GPR-03A-10	GPR-03A-11	GPR-03A-12	GPR-03A-13	GPR-03A-14
Long (Smooth)	400	1397	755	444	1721	11621	6873	5768	12568	4008	10795	4504	25084	7402
Long (Sinuate)	47	243	136	70	186	474	1195	240	150	332	1080	415	1394	346
Long (Rods)	22	12	118	0	31	119	100	0	0	28	0	0	0	0
Long (Dendritic)	52	207	91	21	140	711	3187	1202	5087	0	4183	474	17187	346
Papillae	0	36	0	0	16	119	299	80	1047	221	0	0	1394	69
Hairs	4	12	27	0	0	237	299	160	0	28	405	0	0	69
Trichomes	22	97	55	12	217	2490	598	961	2394	940	1484	237	2787	346
Bulliform	258	340	373	203	1240	5573	3885	5688	10922	1410	7422	3378	37626	5673
Ovals	9	12	18	12	31	237	0	0	0	0	0	0	929	0
Keystone	142	316	636	191	1675	18380	6673	4086	14662	3732	8501	7348	19045	12176
Crenates	4	24	0	0	0	119	0	80	150	0	135	0	0	0
Bilobes	43	194	100	21	109	2253	3486	1923	7481	111	10255	237	52490	761
Crosses	13	85	18	0	31	237	498	561	748	166	945	0	13006	415
Rondels	34	219	36	12	78	2727	1793	2323	2992	166	1619	711	26942	553
Saddles	26	61	45	8	388	830	996	1923	2843	83	3104	474	7897	1591
Cones	0	12	0	4	62	0	199	80	449	111	405	0	2323	0
Flat Tower	0	0	9	0	0	119	0	0	150	28	405	0	929	0
Horned Tower	4	0	0	0	0	0	0	0	150	0	0	0	465	0
Rice bulliform	4	0	0	0	16	237	0	80	299	0	135	59	465	138
Phragmites bulliform	0	0	0	0	0	0	100	0	0	0	0	59	0	0
Double-peaked glume cell	30	36	9	0	16	237	797	160	299	0	675	237	1858	0
Rice bilobe	4	73	0	0	0	0	100	80	0	0	945	0	465	0

Appendix 7.19 continued: Results table for phytolith absolute density (number per gram of sediment) from Gopalpur.

	GPR-03A-1	GPR-03A-2	GPR-03A-3	GPR-03A-4	GPR-03A-5	GPR-03A-6	GPR-03A-7	GPR-03A-8	GPR-03A-9	GPR-03A-10	GPR-03A-11	GPR-03A-12	GPR-03A-13	GPR-03A-14
Rugulose Spheroid	0	12	0	0	16	119	0	240	449	55	135	178	465	484
Smooth Spheroid	13	36	18	4	31	0	199	160	598	55	405	59	0	138
Elongate	26	24	18	25	31	237	498	0	150	249	135	59	0	0
Tracheids	56	85	45	12	47	356	996	80	299	0	405	119	7432	0
Blocks	0	0	64	0	0	0	100	0	150	0	0	0	0	0
Platey	30	24	64	4	0	0	0	80	150	0	0	59	0	0
Sheet	103	547	600	220	109	474	100	561	1197	221	540	237	3716	138
Scalloped	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Single Jigsaw puzzle	4	0	0	0	16	0	100	160	150	28	0	0	0	69
Total single cells	**1351**	**4106**	**3237**	**1264**	**6202**	**47907**	**33068**	**26678**	**65532**	**11970**	**54110**	**18844**	**223895**	**30717**
Leaf/Stem	43	36	50	0	19	576	1116	216	235	14	855	34	8052	3
Unident Husk	87	49	15	0	5	288	2072	120	86	6	720	20	7432	3
Cereal husk	20	4	0	0	0	51	319	32	0	0	135	0	1239	0
Millet husk	0	0	0	0	0	17	80	16	0	0	0	0	0	0
Rice husk	78	162	0	0	0	864	717	344	513	0	2924	57	3097	23
Rice leaf/stem	0	4	0	0	0	17	80	8	0	0	90	0	774	0
Cyperaceae	0	4	0	0	0	102	120	72	224	0	360	22	310	6

Appendix 7.19 continued: Results table for phytolith absolute density (number per gram of sediment) from Gopalpur.

	GPR-03A-1	GPR-03A-2	GPR-03A-3	GPR-03A-4	GPR-03A-5	GPR-03A-6	GPR-03A-7	GPR-03A-8	GPR-03A-9	GPR-03A-10	GPR-03A-11	GPR-03A-12	GPR-03A-13	GPR-03A-14
Square-cell leaf/stem	0	0	0	0	1	34	80	0	0	6	180	2	0	0
Polyhedron	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polyhedral hair base	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesophyll type	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diatoms	0	0	0	0	0	0	0	0	21	0	0	8	0	0
Silica aggregate	0	154	511	427	48	0	0	32	11	156	0	55	619	17
Indet phytolith	0	0	0	0	0	17	40	0	0	0	0	0	0	0
Total multi-cells	**228**	**413**	**575**	**427**	**74**	**1965**	**4622**	**841**	**1090**	**182**	**5263**	**198**	**21522**	**52**
Total phytoliths	**1579**	**4519**	**3812**	**1691**	**6276**	**49872**	**37690**	**27519**	**66622**	**12151**	**59372**	**19042**	**245418**	**30769**

Appendix 7.20: Results table for phytolith absolute density (number per gram of sediment) from Golbai Sasan.

Single-cell	GBSN-03A-1	GBSN-03A-3	GBSN-03A-4A	GBSN-03A-5	GBSN-03A-7A	GBSN-03A-7B	GBSN-03A-8	GBSN-03A-9	GBSN-03A-10	GBSN-03A-11	GBSN-03A-12	GBSN-03A-13A	GBSN-03A-14A	GBSN-03A-14B	GBSN-03A-14C
Long (Smooth)	5022	9160	2800	4245	12815	2496	6027	45560	10648	50848	8513	14853	17473	12958	22160
Long (Sinuate)	526	1362	478	312	1880	373	328	624	1207	6102	532	495	1915	1178	1919
Long (Rods)	239	0	0	117	0	0	66	0	549	0	213	0	0	294	0
Long (Dendritic)	1913	1733	376	234	3930	186	262	10610	1866	7458	1915	1980	3830	687	3839
Papillae	0	0	0	39	0	0	131	0	220	0	106	0	0	393	0
Hairs	0	0	68	117	2563	112	131	1872	0	1356	106	248	0	294	0
Trichomes	191	371	273	78	513	261	197	4993	439	4068	213	1485	957	98	2792
Bulliform	7222	7303	1434	2960	13670	2384	4521	18099	3622	31865	8406	16090	10771	6577	13261
Ovals	96	0	0	39	0	0	197	0	0	0	0	0	0	98	0
Keystone	6601	7055	3653	6192	18625	4806	7731	35575	6696	37288	8406	26982	19149	17866	21462
Crenates	0	248	0	39	0	0	66	624	110	0	0	0	0	0	523
Bilobes	813	4951	478	234	3759	261	328	26837	4171	23051	2022	4703	1436	1571	4188
Crosses	48	866	34	39	513	37	0	2496	439	2034	426	248	239	294	523
Rondels	143	1238	580	389	1196	335	459	16851	1647	12881	958	1980	957	2258	3490
Saddles	526	1238	717	623	2221	261	328	13106	878	6102	851	495	2394	4712	3315
Cones	0	124	34	0	171	0	197	1872	220	678	213	0	0	393	349
Flat Tower	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Horned Tower	48	0	0	0	0	0	0	0	0	0	0	0	0	294	0
Rice bulliform	430	0	0	117	513	149	0	624	439	678	745	495	0	98	523
Phragmites bulliform	0	0	0	0	0	0	0	0	439	0	106	0	0	0	0
Double-peaked glume cell	0	495	0	234	513	75	328	3121	1317	3390	1171	495	479	0	0
Rice bilobe	0	248	0	0	1196	37	0	3121	439	4068	106	248	239	0	698

Appendix 7.20: Results table for phytolith absolute density (number per gram of sediment) from Golbai Sasan.

	GBSN-03A-1	GBSN-03A-3	GBSN-03A-4A	GBSN-03A-5	GBSN-03A-7A	GBSN-03A-7B	GBSN-03A-8	GBSN-03A-9	GBSN-03A-10	GBSN-03A-11	GBSN-03A-12	GBSN-03A-13A	GBSN-03A-14A	GBSN-03A-14B	GBSN-03A-14C
Rugulose Spheroid	430	248	205	78	0	0	131	1248	220	678	319	248	0	196	1396
Smooth Spheroid	96	0	102	39	1196	75	66	1248	329	2034	213	248	718	196	1221
Elongate	48	371	171	195	171	75	328	624	329	1356	532	495	0	393	174
Tracheids	143	743	68	39	342	0	131	1872	659	6102	532	248	239	0	872
Blocks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Platey	48	248	0	39	171	75	131	0	220	0	213	248	239	98	0
Sheet	335	1362	68	389	1880	75	590	1248	1317	5424	1064	743	479	1963	349
Single Polyhedron	0	0	0	0	342	0	0	0	0	0	0	0	0	0	0
Scalloped	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Single Jigsaw puzzle	0	0	34	78	0	37	0	0	0	0	0	1238	0	0	0
Total single cells:	**24920**	**39362**	**11575**	**16863**	**68177**	**12108**	**22668**	**192227**	**38420**	**207458**	**37882**	**74263**	**61516**	**52910**	**83056**
Leaf/Stem	211	920	111	120	911	21	83	7489	1098	7458	1915	2352	957	189	1658
Unident Husk	262	1096	171	142	740	213	143	7177	2744	16949	1561	1361	559	294	785
Cereal husk	8	141	60	50	456	53	179	2184	2195	5085	1703	866	319	631	349
Millet husk	0	0	0	0	0	21	24	0	0	0	426	0	0	63	0
Phragmites Stem	17	0	0	0	0	0	0	624	0	0	0	0	40	0	0
Rice husk	211	1132	376	212	2563	681	750	24340	4501	29153	3547	8788	2074	568	6107
Rice leaf/stem	25	35	17	7	0	0	12	312	110	2034	284	866	120	0	262
Cyperaceae	34	35	85	28	513	11	0	0	0	339	0	248	160	126	87
Square-cell leaf/stem	34	106	9	14	114	0	12	0	110	339	284	0	40	63	87

Appendix 7.20: Results table for phytolith absolute density (number per gram of sediment) from Golbai Sasan.

	GBSN-03A-1	GBSN-03A-3	GBSN-03A-4A	GBSN-03A-5	GBSN-03A-7A	GBSN-03A-7B	GBSN-03A-8	GBSN-03A-9	GBSN-03A-10	GBSN-03A-11	GBSN-03A-12	GBSN-03A-13A	GBSN-03A-14A	GBSN-03A-14B	GBSN-03A-14C
Polyhedron	0	0	0	0	0	0	0	0	0	339	0	0	0	0	0
Mesophyll type	0	0	0	0	513	32	0	312	0	0	0	0	40	0	436
Diatoms	0	0	0	0	171	0	0	0	0	0	0	0	40	0	87
Silica aggregates	59	248	34	170	0	43	131	312	659	0	71	0	0	210	0
Indet multi-cell type 1	0	0	0	7	0	0	12	624	0	0	0	0	0	0	0
Total multi-cells:	**861**	**3713**	**862**	**751**	**5980**	**1075**	**1346**	**43376**	**11416**	**61695**	**9790**	**14481**	**4348**	**2146**	**9859**
Total phytoliths	**25781**	**43075**	**12437**	**17614**	**74158**	**13184**	**24014**	**235603**	**49837**	**269154**	**47671**	**88744**	**65864**	**55056**	**92915**

Appendix 7.21: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Bajpur.

Sample number	0	1	2	3	4
Long (Smooth)	19.8%	33.8%	30.5%	21.7%	25.2%
Long (Sinuate)	2.6%	1.0%	1.5%	3.0%	2.8%
Long (Rods)	0.0%	0.0%	0.0%	0.0%	0.0%
Long (Dendritic)	0.8%	0.6%	0.4%	0.5%	0.2%
Papillae	0.2%	0.0%	0.0%	0.0%	0.2%
Hairs	0.0%	0.0%	0.2%	0.5%	0.3%
Trichomes	2.6%	2.7%	2.1%	2.2%	1.9%
Bulliform	27.6%	13.6%	13.9%	16.2%	15.0%
Ovals	0.4%	1.0%	0.6%	0.8%	0.0%
Keystone	36.5%	40.7%	43.6%	46.2%	45.4%
Crenates	0.0%	0.0%	0.0%	0.0%	0.0%
Bilobes	2.0%	0.6%	0.4%	0.5%	0.2%
Crosses	0.2%	0.0%	0.0%	0.0%	0.0%
Rondels	0.0%	0.4%	0.6%	1.6%	0.3%
Saddles	2.0%	2.9%	3.0%	3.8%	3.1%
Cones	0.4%	0.0%	0.0%	0.3%	0.2%
Flat Tower	0.0%	0.0%	0.0%	0.3%	0.0%
Horned Tower	0.2%	0.0%	0.2%	0.0%	0.0%
Rice bulliform	1.4%	0.2%	0.2%	0.0%	0.0%
Phragmites bulliform	0.2%	0.0%	0.0%	0.0%	0.0%
Double-peaked glume cell	0.0%	0.0%	0.0%	0.0%	0.0%
Rice bilobe	0.2%	0.0%	0.0%	0.0%	0.0%
Rugulose Spheroid	0.6%	0.2%	1.1%	1.1%	0.3%
Smooth Spheroid	0.4%	0.4%	0.4%	0.0%	0.2%
Elongate	0.6%	0.4%	0.7%	0.8%	1.9%
Tracheids	0.6%	0.0%	0.0%	0.0%	0.0%
Blocks	0.2%	1.0%	0.4%	0.0%	0.5%
Platey	0.4%	0.0%	0.0%	0.0%	0.3%
Sheet	0.0%	0.0%	0.4%	0.3%	1.4%
Scalloped	0.0%	0.2%	0.0%	0.0%	0.5%
Single Jigsaw puzzle	0.2%	0.0%	0.0%	0.0%	0.0%

Appendix 7.21 continued: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Bajpur.

Sample number	0	1	2	3	4
Leaf/Stem	11.4%	0.0%	13.6%	0.0%	0.0%
Unident Husk	2.9%	0.0%	0.0%	0.0%	0.0%
Cereal husk	0.0%	0.0%	0.0%	0.0%	0.0%
Millet husk	0.0%	0.0%	0.0%	0.0%	0.0%
Rice husk	5.7%	0.0%	0.0%	0.0%	0.0%
Rice leaf/stem	0.0%	0.0%	0.0%	0.0%	0.0%
Cyperaceae	11.4%	0.0%	0.0%	0.0%	0.0%
Square-cell leaf/stem	0.0%	0.0%	0.0%	0.0%	0.0%
Mesophyll type	0.0%	0.0%	0.0%	0.0%	0.0%
Diatoms	0.0%	0.0%	0.0%	0.0%	0.0%
Silica aggregate	68.6%	100.0%	86.4%	92.9%	100.0%
Indet multi-cell	0.0%	0.0%	0.0%	7.1%	0.0%

Appendix 7.22: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Malakhoja.

Sample number	1	4	7	9
Long (Smooth)	33.0%	23.5%	32.5%	32.6%
Long (Sinuate)	2.2%	2.0%	1.4%	3.4%
Long (Rods)	0.0%	0.0%	0.0%	0.0%
Long (Dendritic)	0.5%	0.8%	1.0%	0.3%
Papillae	0.3%	0.0%	0.0%	0.0%
Hairs	0.0%	0.0%	0.0%	0.0%
Trichomes	1.9%	2.0%	1.4%	2.3%
Bulliform	16.8%	11.8%	13.0%	14.8%
Ovals	0.5%	0.0%	0.0%	0.3%
Keystone	37.8%	44.0%	42.7%	36.6%
Crenates	0.0%	0.0%	0.0%	0.0%
Bilobes	0.5%	0.3%	0.0%	0.3%
Crosses	0.0%	0.0%	0.0%	0.0%
Rondels	0.5%	1.1%	2.7%	0.0%
Saddles	2.7%	6.2%	2.2%	1.7%
Cones	0.0%	0.0%	0.0%	0.0%
Flat Tower	0.0%	0.0%	0.0%	0.0%
Horned Tower	0.0%	0.0%	0.0%	0.0%
Rice bulliform	0.0%	0.0%	0.0%	0.0%
Phragmites bulliform	0.0%	0.0%	0.0%	0.0%
Double-peaked glume cell	0.0%	0.0%	0.0%	0.0%
Rice bilobe	0.0%	0.0%	0.0%	0.0%
Rugulose Spheroid	0.0%	0.3%	0.0%	0.0%
Smooth Spheroid	0.0%	0.0%	0.0%	0.0%
Elongate	0.8%	0.8%	0.5%	1.3%
Tracheids	0.0%	0.0%	0.0%	0.0%
Blocks	0.8%	5.0%	2.2%	4.0%
Platey	0.0%	0.0%	0.0%	0.0%
Sheet	0.5%	2.0%	0.5%	2.0%
Scalloped	0.3%	0.3%	0.0%	0.3%
Single Jigsaw puzzle	0.8%	0.0%	0.0%	0.0%

Appendix 7.22 continued: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Malakhoja.

Sample number	**1**	**4**	**7**	**9**
Leaf/Stem	25.0%	4.8%	0.0%	0.0%
Unident Husk:	0.0%	0.0%	0.0%	3.1%
Cereal husk	0.0%	0.0%	0.0%	0.0%
Millet husk	0.0%	0.0%	0.0%	0.0%
Rice husk:	0.0%	0.0%	0.0%	0.0%
Rice leaf/stem	0.0%	0.0%	0.0%	0.0%
Cyperaceae	0.0%	0.0%	0.0%	3.1%
Square-cell leaf/stem	0.0%	0.0%	0.0%	0.0%
Mesophyll type	0.0%	0.0%	0.0%	0.0%
Diatoms	0.0%	0.0%	0.0%	0.0%
Silica aggregate	75.0%	95.2%	100.0%	93.8%

Appendix 7.23: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Gopalpur.

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Long (Smooth)	29.6%	34.0%	23.3%	35.1%	27.8%	24.3%	20.8%	21.6%	19.2%	33.5%	20.0%	23.9%	11.2%	24.1%
Long (Sinuate)	3.5%	5.9%	4.2%	5.6%	3.0%	1.0%	3.6%	0.9%	0.2%	2.8%	2.0%	2.2%	0.6%	1.1%
Long (Rods)	1.6%	0.3%	3.7%	0.0%	0.5%	0.2%	0.3%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
Long (Dendritic)	3.8%	5.0%	2.8%	1.6%	2.3%	1.5%	9.6%	4.5%	7.8%	0.0%	7.7%	2.5%	7.7%	1.1%
Papillae	0.0%	0.9%	0.0%	0.0%	0.3%	0.2%	0.9%	0.3%	1.6%	1.8%	0.0%	0.0%	0.6%	0.2%
Hairs	0.3%	0.3%	0.8%	0.0%	0.0%	0.5%	0.9%	0.6%	0.0%	0.2%	0.7%	0.0%	0.0%	0.2%
Trichomes	1.6%	2.4%	1.7%	1.0%	3.5%	5.2%	1.8%	3.6%	3.7%	7.9%	2.7%	1.3%	1.2%	1.1%
Bulliform	19.1%	8.3%	11.5%	16.1%	20.0%	11.6%	11.7%	21.3%	16.7%	11.8%	13.7%	17.9%	16.8%	18.5%
Ovals	0.6%	0.3%	0.6%	1.0%	0.5%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%
Keystone	10.5%	7.7%	19.7%	15.1%	27.0%	38.4%	20.2%	15.3%	22.4%	31.2%	15.7%	39.0%	8.5%	39.6%
Crenates	0.3%	0.6%	0.0%	0.0%	0.0%	0.2%	0.0%	0.3%	0.2%	0.0%	0.2%	0.0%	0.0%	0.0%
Bilobes	3.2%	4.7%	3.1%	1.6%	1.8%	4.7%	10.5%	7.2%	11.4%	0.9%	19.0%	1.3%	23.4%	2.5%
Crosses	1.0%	2.1%	0.6%	0.0%	0.5%	0.5%	1.5%	2.1%	1.1%	1.4%	1.7%	0.0%	5.8%	1.4%
Rondels	2.5%	5.3%	1.1%	1.0%	1.3%	5.7%	5.4%	8.7%	4.6%	1.4%	3.0%	3.8%	12.0%	1.8%
Saddles	1.9%	1.5%	1.4%	0.7%	6.3%	1.7%	3.0%	7.2%	4.3%	0.7%	5.7%	2.5%	3.5%	5.2%
Cones	0.0%	0.3%	0.0%	0.3%	1.0%	0.0%	0.6%	0.3%	0.7%	0.9%	0.7%	0.0%	1.0%	0.0%
Flat Tower	0.0%	0.0%	0.3%	0.0%	0.0%	0.2%	0.0%	0.0%	0.2%	0.2%	0.7%	0.0%	0.4%	0.0%
Horned Tower	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.2%	0.0%
Rice bulliform	0.3%	0.0%	0.0%	0.0%	0.3%	0.5%	0.0%	0.3%	0.5%	0.0%	0.2%	0.3%	0.2%	0.5%
Phragmites bulliform	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%
Double-peaked glume cell	2.2%	0.9%	0.3%	0.0%	0.3%	0.5%	2.4%	0.6%	0.5%	0.0%	1.2%	1.3%	0.8%	0.0%
Rice bilobe	0.3%	1.8%	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%	0.0%	0.0%	1.7%	0.0%	0.2%	0.0%

Appendix 7.23 continued: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Gopalpur.

Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rugulose Spheroid	0.0%	0.3%	0.0%	0.0%	0.3%	0.2%	0.0%	0.9%	0.7%	0.5%	0.2%	0.9%	0.2%	1.6%
Smooth Spheroid	1.0%	0.9%	0.6%	0.3%	0.5%	0.0%	0.6%	0.6%	0.9%	0.5%	0.7%	0.3%	0.0%	0.5%
Elongate	1.9%	0.6%	0.6%	2.0%	0.5%	0.5%	1.5%	0.0%	0.2%	2.1%	0.2%	0.3%	0.0%	0.0%
Tracheids	4.1%	2.1%	1.4%	1.0%	0.8%	0.7%	3.0%	0.3%	0.5%	0.0%	0.7%	0.6%	3.3%	0.0%
Blocks	0.0%	0.0%	2.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Platey	2.2%	0.6%	2.0%	0.3%	0.0%	0.0%	0.0%	0.3%	0.2%	0.0%	0.0%	0.3%	0.0%	0.0%
Sheet	7.6%	13.3%	18.5%	17.4%	1.8%	1.0%	0.3%	2.1%	1.8%	1.8%	1.0%	1.3%	1.7%	0.5%
Single Jigsaw puzzle	0.3%	0.0%	0.0%	0.0%	0.3%	0.0%	0.3%	0.6%	0.2%	0.2%	0.0%	0.0%	0.0%	0.2%
Leaf/Stem	18.6%	8.8%	8.6%	0.0%	26.3%	29.3%	24.1%	25.7%	21.6%	7.6%	16.2%	17.0%	37.4%	5.6%
Unident Husk	38.2%	11.8%	2.6%	0.0%	7.0%	14.7%	44.8%	14.3%	7.8%	3.3%	13.7%	10.0%	34.5%	5.6%
Cereal husk	8.8%	1.0%	0.0%	0.0%	0.0%	2.6%	6.9%	3.8%	0.0%	0.0%	2.6%	0.0%	5.8%	0.0%
Millet husk	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	1.7%	1.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Rice husk	0.0%	39.2%	0.0%	0.0%	0.0%	44.0%	15.5%	41.0%	47.1%	0.0%	55.6%	29.0%	14.4%	44.4%
Rice leaf/stem	0.0%	1.0%	0.0%	0.0%	0.0%	0.9%	1.7%	1.0%	0.0%	0.0%	1.7%	0.0%	3.6%	0.0%
Cyperaceae	34.3%	1.0%	0.0%	0.0%	0.0%	5.2%	2.6%	8.6%	20.6%	0.0%	6.8%	11.0%	1.4%	11.1%
Square-cell leaf/stem	0.0%	0.0%	0.0%	0.0%	1.8%	1.7%	1.7%	0.0%	0.0%	3.3%	3.4%	1.0%	0.0%	0.0%
Diatoms	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.0%	0.0%	0.0%	4.0%	0.0%	0.0%
Silica aggregate	0.0%	37.3%	88.8%	100%	64.9%	0.0%	0.0%	3.8%	1.0%	85.9%	0.0%	28.0%	2.9%	33.3%
Indet phytolith	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Appendix 7.24: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Golbai Sasan.

Sample number	1	3	4A	5	7A	7B	8	9	10	11	12	13A	14A	14B	14C
Long (Smooth):	20.2%	23.3%	24.2%	25.2%	18.8%	20.6%	26.6%	23.7%	27.7%	24.5%	22.5%	20.0%	28.4%	24.5%	26.7%
Long (Sinuate)	2.1%	3.5%	4.1%	1.8%	2.8%	3.1%	1.4%	0.3%	3.1%	2.9%	1.4%	0.7%	3.1%	2.2%	2.3%
Long (Rods)	1.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.3%	0.0%	1.4%	0.0%	0.6%	0.0%	0.0%	0.6%	0.0%
Long (Dendritic):	7.7%	4.4%	3.2%	1.4%	5.8%	1.5%	1.2%	5.5%	4.9%	3.6%	5.1%	2.7%	6.2%	1.3%	4.6%
Papillae:	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.6%	0.0%	0.6%	0.0%	0.3%	0.0%	0.0%	0.7%	0.0%
Hairs:	0.0%	0.0%	0.6%	0.7%	3.8%	0.9%	0.6%	1.0%	0.0%	0.7%	0.3%	0.3%	0.0%	0.6%	0.0%
Trichomes:	0.8%	0.9%	2.4%	0.5%	0.8%	2.2%	0.9%	2.6%	1.1%	2.0%	0.6%	2.0%	1.6%	0.2%	3.4%
Bulliform:	29.0%	18.6%	12.4%	17.6%	20.1%	19.7%	19.9%	9.4%	9.4%	15.4%	22.2%	21.7%	17.5%	12.4%	16.0%
Ovals	0.4%	0.0%	0.0%	0.2%	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%
Keystone	26.5%	17.9%	31.6%	36.7%	27.3%	39.7%	34.1%	18.5%	17.4%	18.0%	22.2%	36.3%	31.1%	33.8%	25.8%
Crenates:	0.0%	0.6%	0.0%	0.2%	0.0%	0.0%	0.3%	0.3%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
Bilobes:	3.3%	12.6%	4.1%	1.4%	5.5%	2.2%	1.4%	14.0%	10.9%	11.1%	5.3%	6.3%	2.3%	3.0%	5.0%
Crosses:	0.2%	2.2%	0.3%	0.2%	0.8%	0.3%	0.0%	1.3%	1.1%	1.0%	1.1%	0.3%	0.4%	0.6%	0.6%
Rondels:	0.6%	3.1%	5.0%	2.3%	1.8%	2.8%	2.0%	8.8%	4.3%	6.2%	2.5%	2.7%	1.6%	4.3%	4.2%
Saddles:	2.1%	3.1%	6.2%	3.7%	3.3%	2.2%	1.4%	6.8%	2.3%	2.9%	2.2%	0.7%	3.9%	8.9%	4.0%
Cones:	0.0%	0.3%	0.3%	0.0%	0.3%	0.0%	0.9%	1.0%	0.6%	0.3%	0.6%	0.0%	0.0%	0.7%	0.4%
Flat Tower:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Horned Tower:	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%
Rice bulliform:	1.7%	0.0%	0.0%	0.7%	0.8%	1.2%	0.0%	0.3%	1.1%	0.3%	2.0%	0.7%	0.0%	0.2%	0.6%
Phragmites bulliform:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
Double-peaked glume cell:	0.0%	1.3%	0.0%	1.4%	0.8%	0.6%	1.4%	1.6%	3.4%	1.6%	3.1%	0.7%	0.8%	0.0%	0.0%
Rice bilobe:	0.0%	0.6%	0.0%	0.0%	1.8%	0.3%	0.0%	1.6%	1.1%	2.0%	0.3%	0.3%	0.4%	0.0%	0.8%

Appendix 7.24 continued: Table of relative frequencies of single-celled and multi-celled phytolith types calculated using the total number of single-celled phytoliths and total multi-celled phytoliths respectively for Golbai Sasan.

Sample number	1	3	4A	5	7A	7B	8	9	10	11	12	13A	14A	14B	14C
Rugulose Spheroid	1.7%	0.6%	1.8%	0.5%	0.0%	0.0%	0.6%	0.6%	0.6%	0.3%	0.8%	0.3%	0.0%	0.4%	1.7%
Smooth Spheroid	0.4%	0.0%	0.9%	0.2%	1.8%	0.6%	0.3%	0.6%	0.9%	1.0%	0.6%	0.3%	1.2%	0.4%	1.5%
Elongate	0.2%	0.9%	1.5%	1.2%	0.3%	0.6%	1.4%	0.3%	0.9%	0.7%	1.4%	0.7%	0.0%	0.7%	0.2%
Tracheids	0.6%	1.9%	0.6%	0.2%	0.5%	0.0%	0.6%	1.0%	1.7%	2.9%	1.4%	0.3%	0.4%	0.0%	1.1%
Blocks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Leaf/Stem:	24.5%	24.8%	12.9%	16.0%	15.2%	2.0%	6.2%	17.3%	9.6%	12.1%	19.6%	16.2%	22.0%	8.8%	16.8%
Unident Husk:	30.4%	29.5%	19.8%	18.9%	12.4%	19.8%	10.6%	16.5%	24.0%	27.5%	15.9%	9.4%	12.8%	13.7%	8.0%
Cereal husk:	1.0%	3.8%	6.9%	6.6%	7.6%	5.0%	13.3%	5.0%	19.2%	8.2%	17.4%	6.0%	7.3%	29.4%	3.5%
Millet husk:	0.0%	0.0%	0.0%	0.0%	0.0%	2.0%	1.8%	0.0%	0.0%	0.0%	4.3%	0.0%	0.0%	2.9%	0.0%
Phragmites Stem	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.9%	0.0%	0.0%
Rice husk:	24.5%	30.5%	43.6%	28.3%	42.9%	63.4%	55.8%	56.1%	39.4%	47.3%	36.2%	60.7%	47.7%	26.5%	61.9%
Rice leaf/stem	2.9%	1.0%	2.0%	0.9%	0.0%	0.0%	0.9%	0.7%	1.0%	3.3%	2.9%	6.0%	2.8%	0.0%	2.7%
Cyperaceae	3.9%	1.0%	9.9%	3.8%	8.6%	1.0%	0.0%	0.0%	0.0%	0.5%	0.0%	1.7%	3.7%	5.9%	0.9%
Square-cell leaf/stem	3.9%	2.9%	1.0%	1.9%	1.9%	0.0%	0.9%	0.0%	1.0%	0.5%	2.9%	0.0%	0.9%	2.9%	0.9%
Polyhedron	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%
Mesophyll type	0.0%	0.0%	0.0%	0.0%	8.6%	3.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.9%	0.0%	4.4%
Diatoms	0.0%	0.0%	0.0%	0.0%	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	0.0%	0.9%
Silica aggregate	6.9%	6.7%	4.0%	22.6%	0.0%	4.0%	9.7%	0.7%	5.8%	0.0%	0.7%	0.0%	0.0%	9.8%	0.0%
Indet multi-cell type 1	0.0%	0.0%	0.0%	0.9%	0.0%	0.0%	0.9%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Early Agricultural Communities in Northern and Eastern India: an archaeobotanical investigation.

Volume II

Emma Louise Harvey

Thesis submitted in fulfilment of the requirements of the degree of Doctor of Philosophy in the Institute of Archaeology, University of London.

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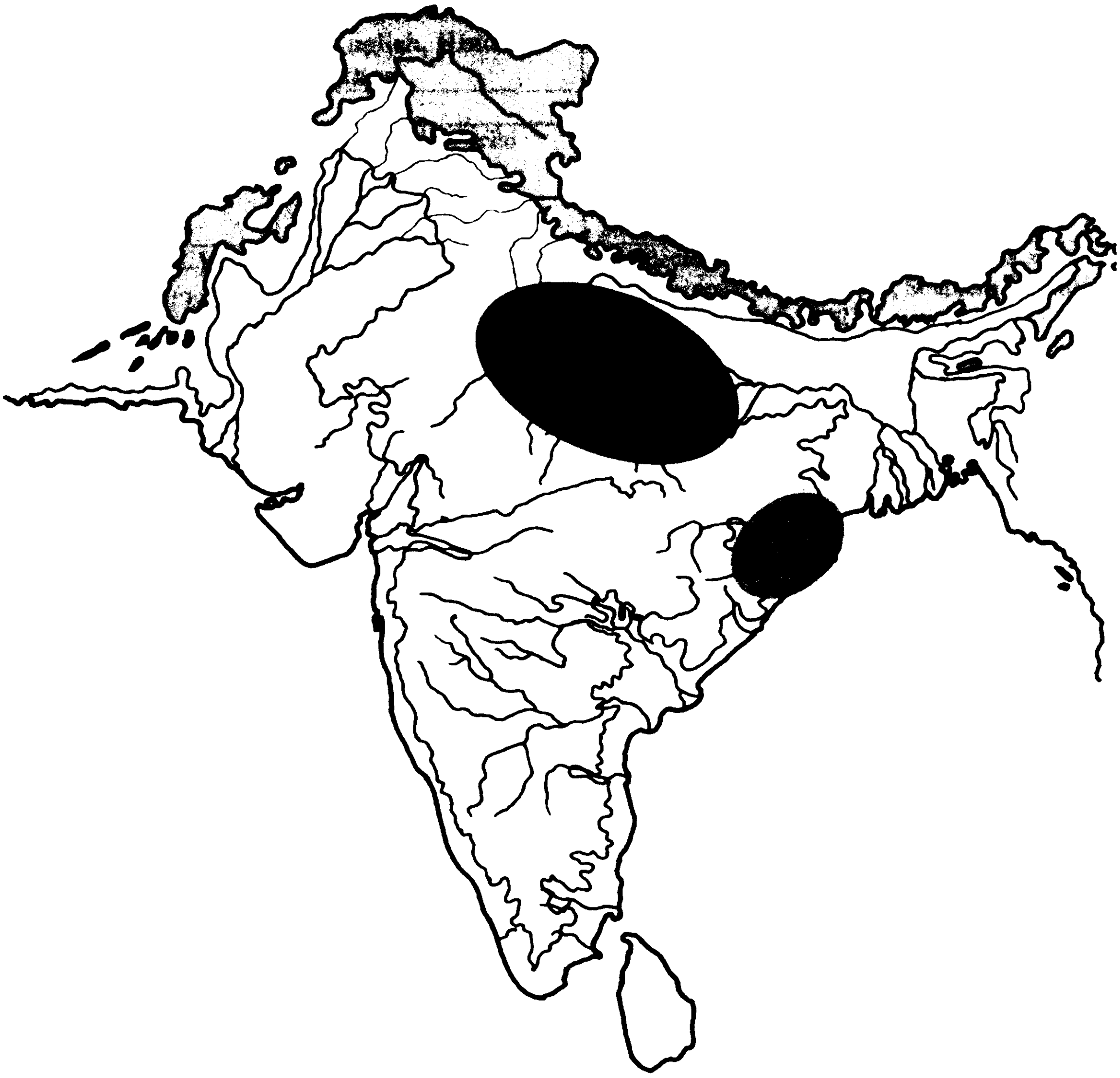


Figure 1.1: Map of India showing the areas of study in this project. 1. Ganges River Valley; 2. Orissa.

Crop	Common name English, Hindi, other	Region of origin
Cereals		
Oryza sativa L. subsp *indica*	Rice, paddy, vrihi	Tract from central Uttar Pradesh, through to Chattisgrah, Bihar, west and south Orissa. (Chen et al. 1993, Cheng et al. 2003, Fuller 2002)
Bracharia ramosa (L.) Stapf.	Browntop millet, Pedda Sama	Dry deciduous forest clearings, savanna zone streams, north facing slopes, Southern Neolithic zone (Fuller 1999, 2002)
Echinochloa colona L. Link	Sawa millet, shama	Secondary domestication of Gangetic rice/millet weed (?) (De Wet et al. 1983c)
Paspalum scrobicultum L.	Kodo millet, kodon	Secondary domestication of Gangetic rice weed (?) (De Wet et al. 1983b, De Wet 1995a)
Panicum sumatrense Roth. Ex Roem. & Schult	Little millet, shavan	At least one domestication in Gujurat (?) (De Wet et al. 1983a, De Wet 1995a)
Setaria pumila (Poir) Roem. & Schult.	Yellow foxtail millet, bandhra	Dry deciduous forest clearings, savanna zone streams, north facing slopes (De Wet 1995a)
Setaria verticillata (L.) P. Beauv.	Bristley foxtail millet	Dry deciduous forest clearings, savanna zone streams, north facing slopes, Southern Neolithic zone and Vindhyas (?) (Fuller 1999, 2002)
Pulses		
Cajanus cajan (L.) Millsp.	Pigeon pea, Red Gram, Tuvar	South Orissa, Bastar, Northern Andhra Pradesh (De 1974, van der Maeson 1980, 1986, 1990, 1995, Smartt 1985a, Jha & Ohri 1996)
Macrotyloma uniflorum (Lam.) Verdcourt	Horsegram, Kulthi	South Asia: savannahs or dry deciduous woodlands. Western and/or South India (?) (Jansen 1989, Mehra 1997, Fuller & Harvey in press)
Vigna mungo (L.) Hepper	Black gram, Urd	South Asia. Moist deciduous mainly forest. Northern extent of wild progenitor could include Vindhyas and Orissan hills (Arora et al. 1973, Babu et al. 1988, Fuller & Korisettar 2004, Fuller & Harvey in press)
Vigna radiata (L.)	Green gram, Mung	South Asia. Moist deciduous mainly forest. Northern extent of wild progenitor could include Vindhyas and Orissan hills (Arora et al. 1973, Babu et al. 1988, Fuller & Korisettar 2004, Fuller & Harvey in press)
Gourds (Curcurbits)		
Benincasa hispada (Thunb.) Cogn.	Wax gourd, Petha	Asia, (India?). SW China: Yunnan (Purseglove 1968, Smartt & Simmonds 1995)
Citrullus colycinthus (L.) Schrad.	Wild or bitter gourd	Africa, NE Himalayas, Western & Central India (Purseglove 1968, Heiser 1979, Smartt & Simmonds 1995)
Coccinia grandis L. Voigt.	Ivy gourd, kundari	Wild in Himalayan foothills, hills in central and eastern India (Purseglove 1968, Smartt & Simmonds 1995)

Figure 1.2: Table of possible indigenous Indian crops that could be present on the sites under investigation in Gangetic India and Orissa.

Crop	Common name English, Hindi, other	Region of origin
Gourds continued		
Cucumis melo L.	Melon, Kharbuza	Northern/Western India (?), as well as SW Asia (Bates & Rodibson 1995, Choudhury 1996)
Cucumis sativus L.	Cucumbers, Khira	Wild in Himalayan foothills and also possibly Orissan high hills (Bates & Robinson 1995)
Luffa cylindrical (L.) M.J. Roem.	Sponge gourd, loofah, Ghiya tori, Nenua	Asia, India, Himalayas and SW China (Marr et al. 2005)
Luffa acutangula (L.) Roxb.	Ridged gourd, angled loofah, Kali tori	Wild in Himalayan foothills, hills of central and eastern India (Marr et al. 2005)
Momordica balsamina L.	Balsam apple, mocha	Wild in Himalayan foothills, hills on central and eastern India through to Southeast Asia (Bates et al. 1995)
Momordica charantia L.	Bitter gourd, karela	Wild in Himalayan foothills, hills on central and eastern India through to Southeast Asia (Bates et al. 1995, Marr et al. 2004)
Momordica dioeca Roxb. Ex Willd.	Small bitter gourd, murela, jangli karela	Wild in Himalayan foothills, hills on central and eastern India through to Southeast Asia (Bates et al. 1995)
Praecitrullus fistulosus (Sticks) Pang.	Indian squash melon, Tinda	Wild in Himalayan foothills, hills on central and eastern India (Bates et al. 1995)
Trichosanthes cucumerina L.	Snake gourd, Chichinda	Wild in Himalayan foothills, hills on central and eastern India (Bates et al. 1995)
Trichosanthes dioica Roxb.	Pointed gourd, Parwal	Wild in Himalayan foothills, hills on central and eastern India (Bates et al. 1995)
Tubers		
Colocasia esculenta Schott.	Taro, Ghuiyan, Arvi	Eastern India and/or Southeast Asia (Purseglove 1972)
Dioscorea spp.	Yams, Ratalu	Eastern India and/or Southeast Asia (Purseglove 1972)
Palms (Palmae)		
Borassus flabellifer	Palmyra Palm, Tal	North to Eastern India and Malaya (McCurrah 1960, Davies & Johnson 1987, Basu & Chakraverty 1994)
Cocos nucifera L.	Coconut, Nariel	Coastal and islands of Southeast Asia and the western Pacific (Harries 1995)
Phoenix sylvestris	Date palm, forest date	Western India and Arabian Gulf (Wrigley 1995)
Others		
Musa spp.	Banana	Eastern India, Sri Lanka, New Guinea (Simmonds 1995, Kornel 2006)
Saccharum spp.	Sugarcane, ganna	Wild in Himalayan foothills, India, China, and New Guinea (Daniel & Roach 1987, Roach 1995)
Sesamum indicum L.	Sesame, Til	Western parts of Himalayas, western Pakistan, also wild on west coast of South India (Bedigan 1998, 2003, Fuller 2003b)

Figure 1.2 continued: Table of possible indigenous Indian crops that could be present on the sites under investigation in Gangetic India and Orissa.

Crops	**Common name English, Hindi, other**	**Region of origin**
Cereals		
Oryza sativa L. subsp. *japonica*	Rice, paddy, Vrihi	Southern China (Chen at al. 1993, Fuller 2002, Cheng et al. 2003)
Panicum miliaceum L.	Proso millet, Chin	North China and Europe (?) (Chang 1989, Jones 2004)
Setaria italica (L.) Beauv.	Common foxtail millet, kangu	Northern China (?), also maybe Europe (?) (Jones 2004)
Hordeum vulgare L. sensu lato	Barley, Yava	Near East (Zohary & Hopf 2000)
Triticum spp.	Wheat, Gehu	Near East (Zohary & Hopf 2000)
Eleusine coracana L.	Finger millet, Ragi	Africa (Fuller 2002, 2003c)
Pennisetum glaucum (L.) R. Br.	Pearl millet, Bajra	Africa (Fuller 2002, 2003c)
Sorghum bicolor (L.) Moench.	Great millet, Jowar	Africa (Fuller 2002, 2003c)
Pulses		
Cicer arietinum L.	Chickpea, Gram	Near East (Zohary & Hopf 2000)
Lathyrus sativus L.	Grasspea, Khesari	Near East (Zohary & Hopf 2000)
Lens culinaris L.	Lentil, Masur	Near East (Zohary & Hopf 2000)
Pisum sativum L.	Pea, Matter	Near East (Zohary & Hopf 2000)
Lablab purpureus (L.) Sweet.	Hyacinth bean, Sem	Africa (Fuller 2002, 2003c, Pengelly & Maass 2001, Maass et al. 2005)
Vigna unguiculata (L.) Walp.	Cowpea, Lobia	Africa (Ng 1995, Fuller 2002, 2003c)
Others		
Cannabis sativus L.	Hemp, Ganja	China and or Central Asia (Small 1995)
Linum usitatissimum L.	Flax, Linen, Alsi	Near East (Zohary & Hopf 2000)

Figure 1.3: Table of introduced crops that may be present at the sites under investigation in Gangetic India and Orissa.

	Procurement	Cultivation		Crop production
	Wild plant food procurement	Wild plant food production - Small scale	Wild plant food production - Large scale	Agriculture - cultivation of domestic crops
	Gathering, burning, tending	Replacement planting, harvesting, storage	Land clearance, tillage	Full scale agricultural production
Plant remains	Foragers using wild rice and other grasses	Management of wild rice Emergence of arable weeds		Domestic rice and other crops: maybe increase in seed size
Other evidence	Ceramics	Increased sedentism Seasonal ⟶ Year round		
Indian Gangetic Sites	Damdama Chopani-Mando	? – evidence may be missing	? ⟵ Lahuradewa Senuwar Koldihwa/Mahagara? ⟶ ?	

Figure 2.1: The general expected subsistence stages in the evolution of agriculture and domesticated cereal crops adapted from Harris (1989, 1996), with the possible occurrences on Gangetic sites included at the bottom.

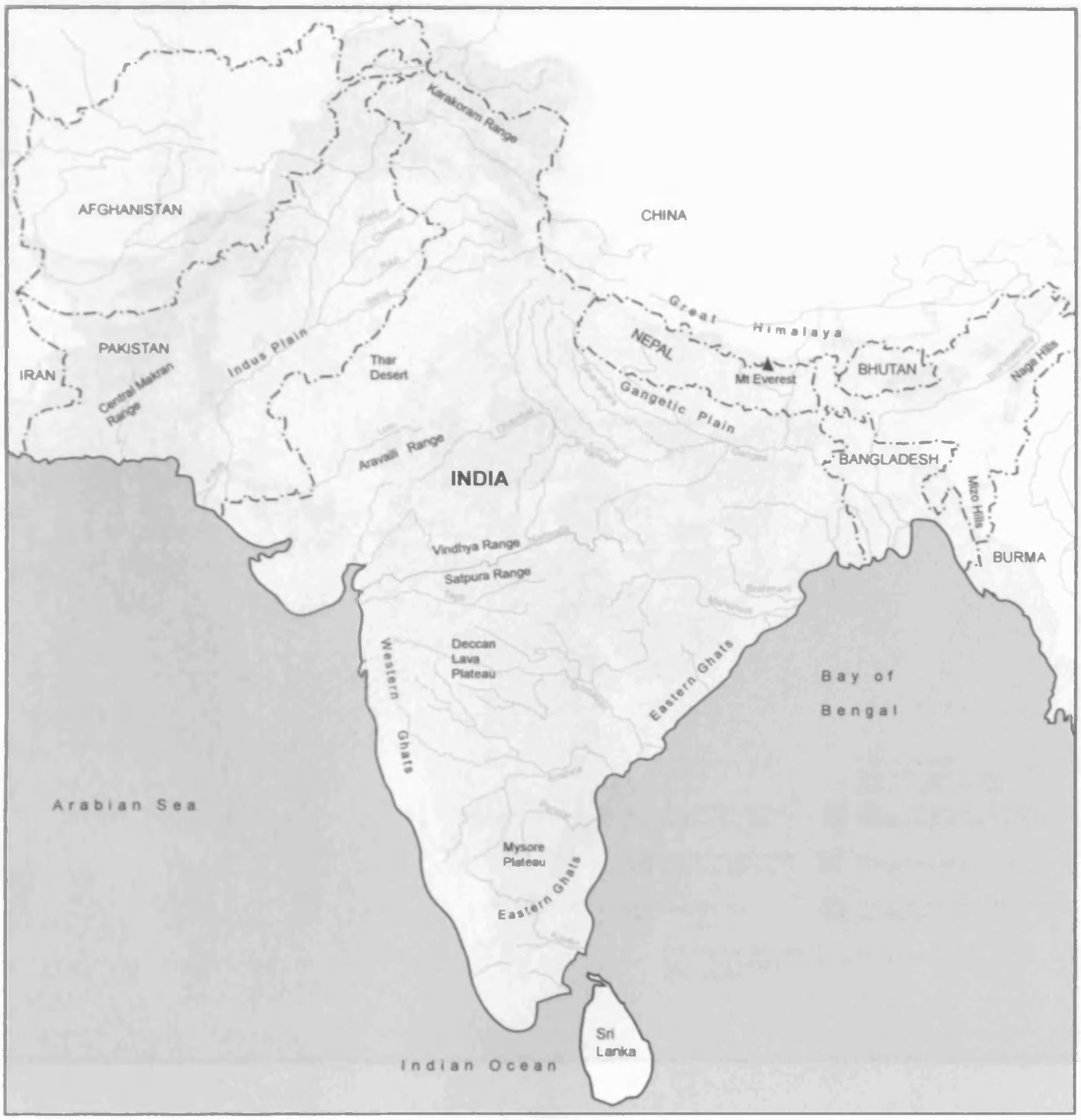


Figure 3.1: Political map of South Asia with geographic features (after Robinson 1989).

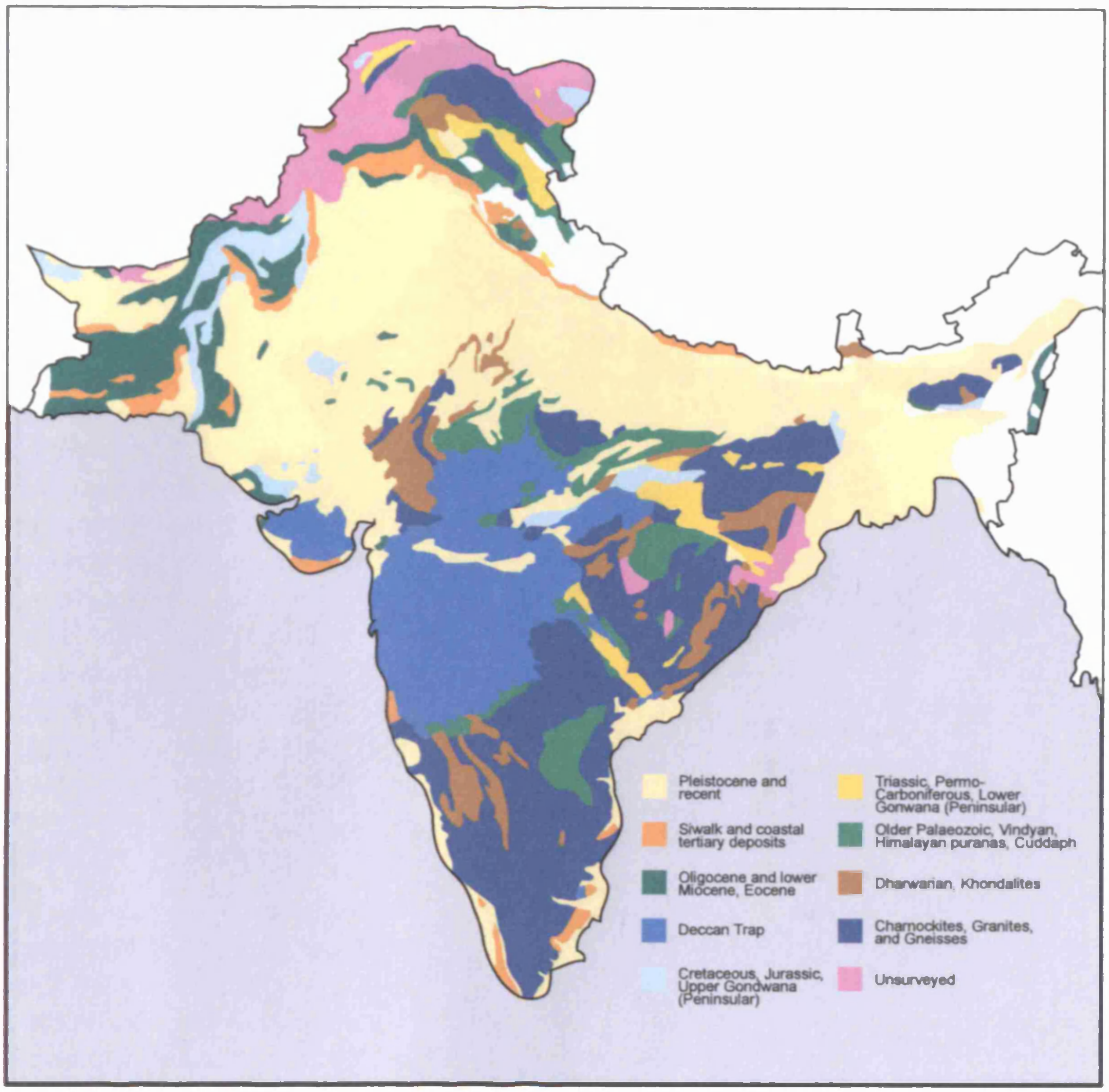


Figure 3.2: Geological map of India (after Robinson 1989).

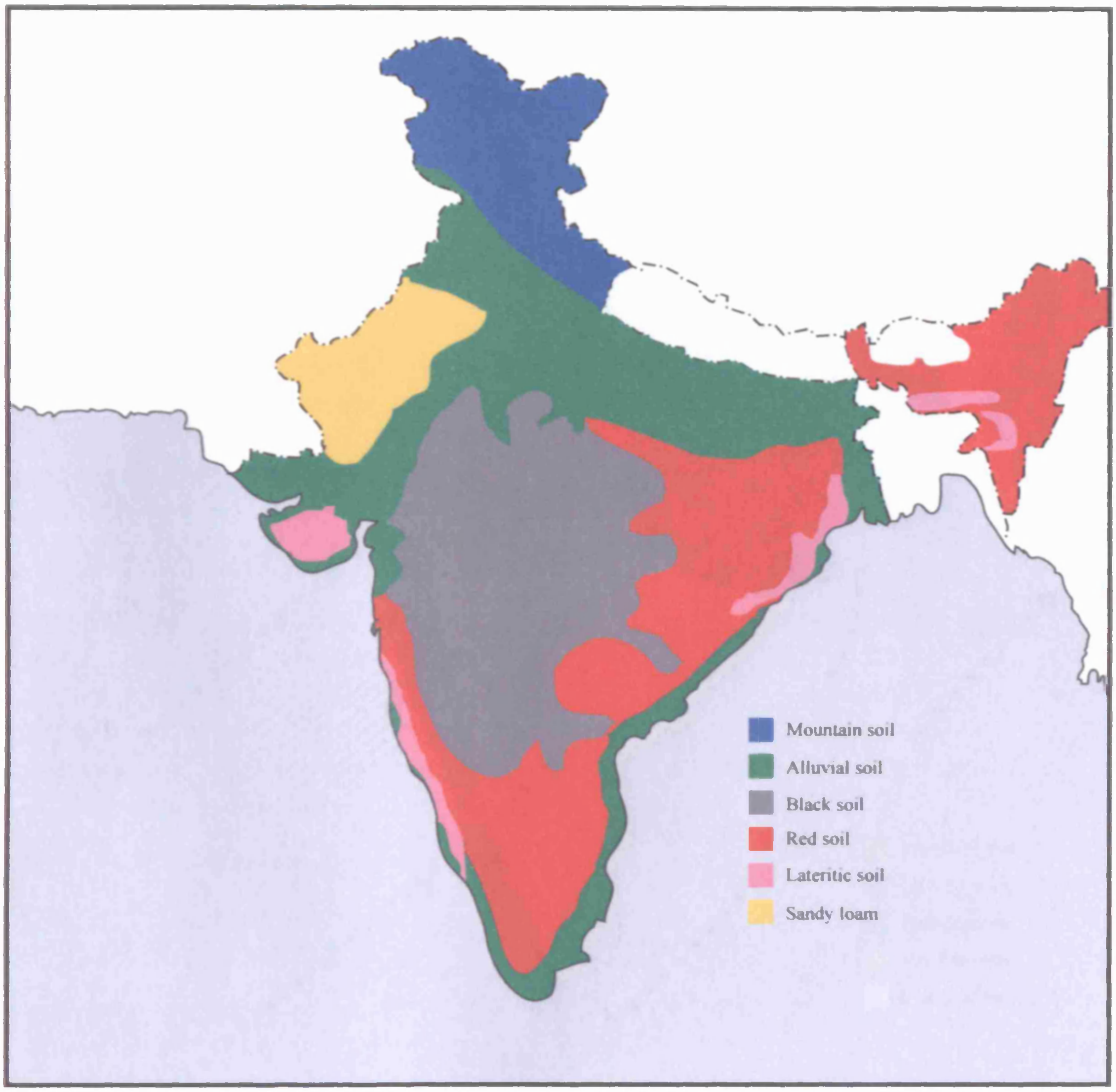


Figure 3.3: Soil map of India (after Qazi 2000).

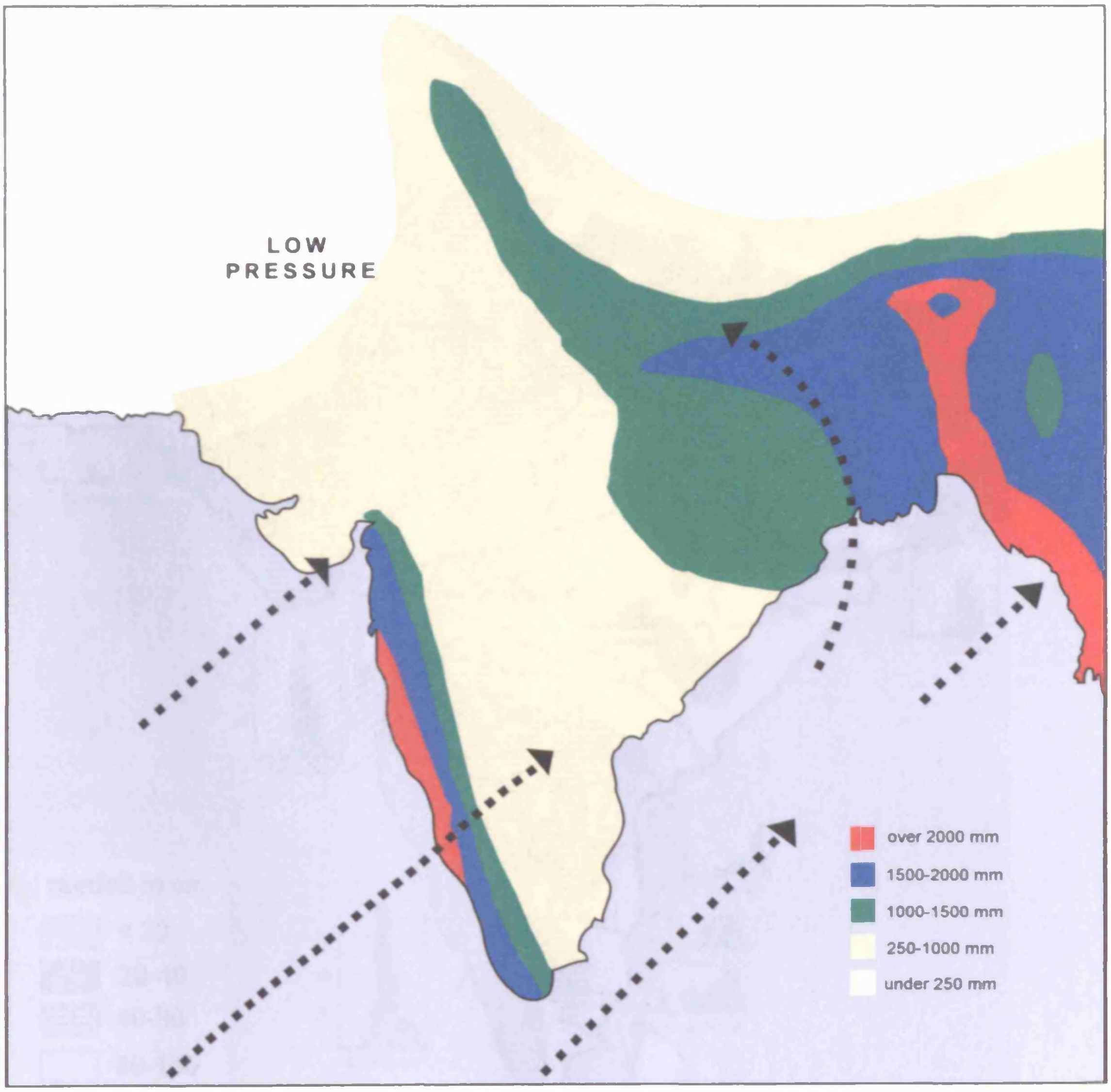


Figure 3.4: Monsoon rainfall map of India (after Robinson 1979).

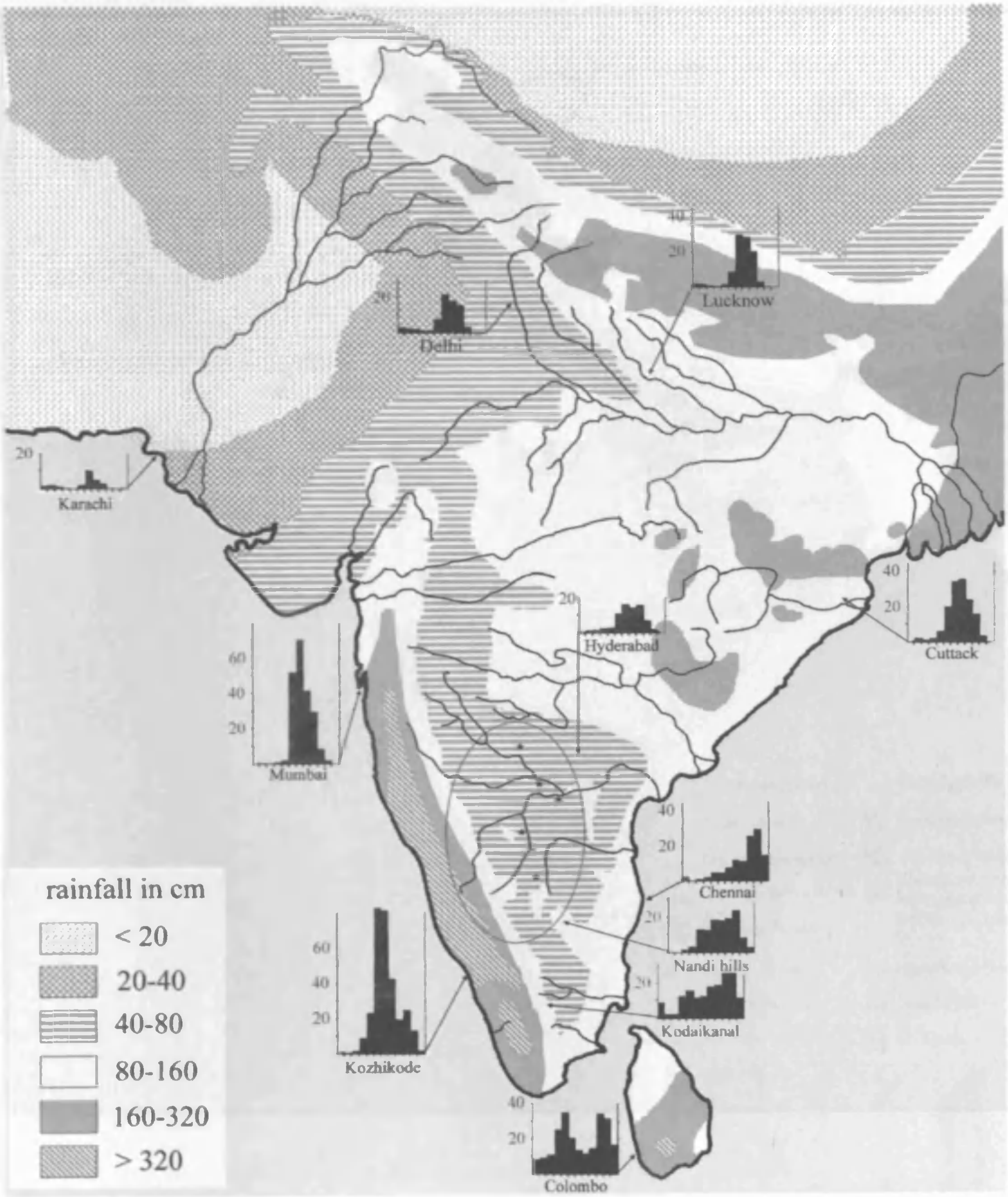


Figure 3.5: Annual rainfall map of India (after Fuller 1999).

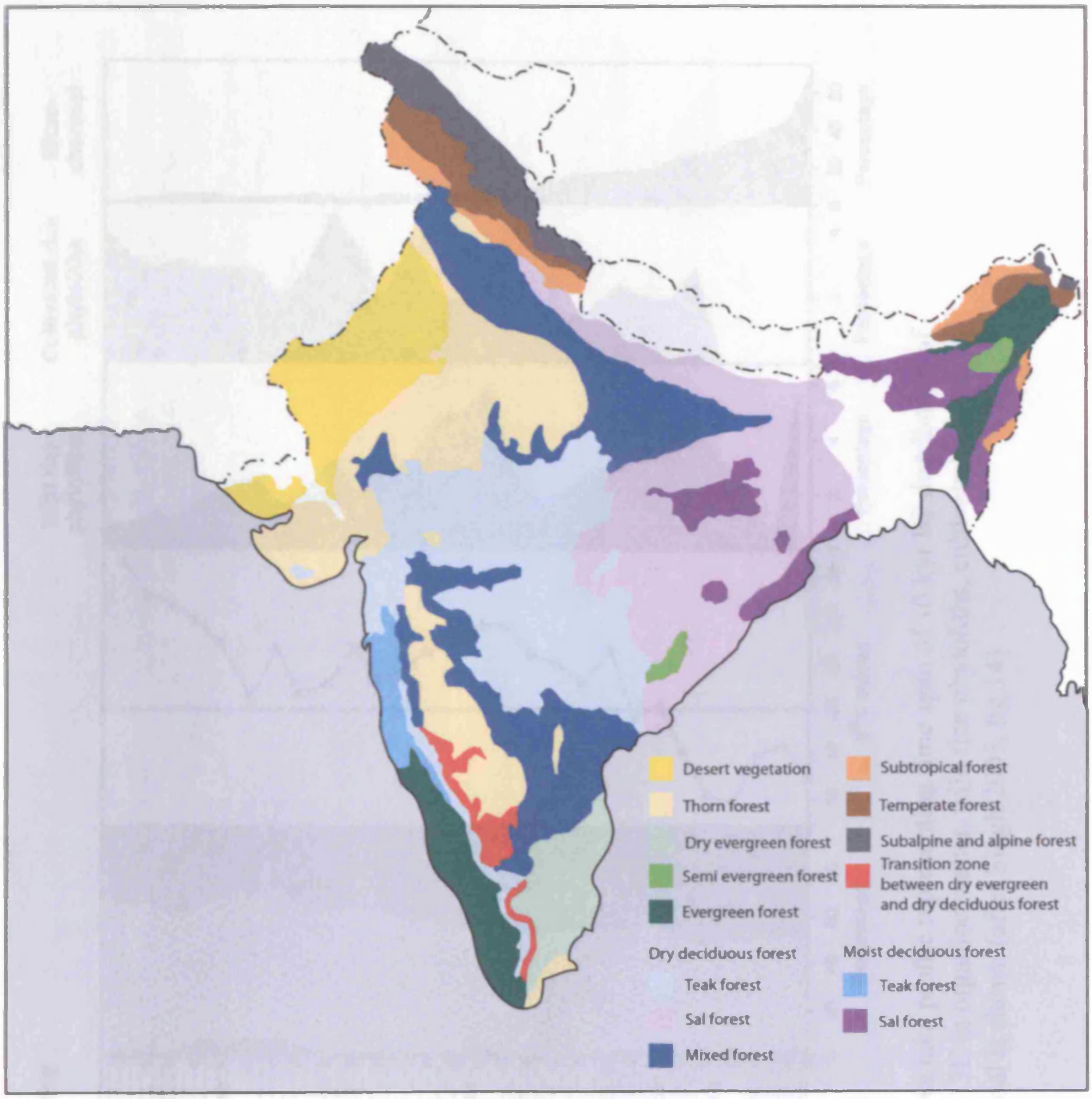


Figure 3.6: Map of the modern vegetation of India (Meher-Homji 1996).

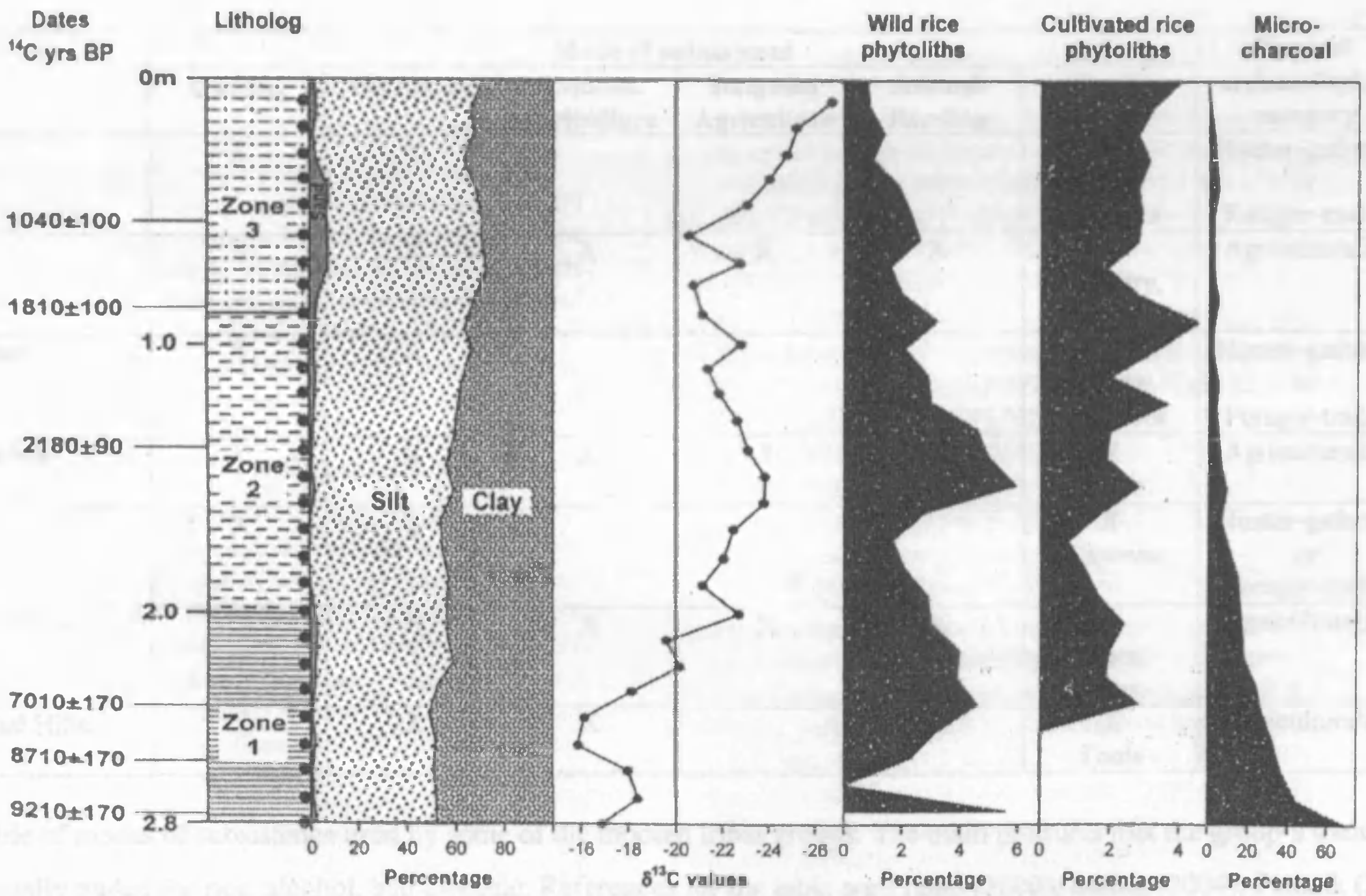


Figure 3.7: Lahuradewa lake profile representing time span of 10 kyr BP distribution of sediment character, d 13C in organioc matter, wild rice phytoliths, cultivated rice phytoliths, and micro charcoal is shown (after Singh 2005, fig.14)

Tribal Group	Mode of subsistence						Typical archaeological category
	Hunting	Gathering	Swidden Agriculture	Irrigated Agriculture	Animal Herding	Trade	
Birhor, Orissa	X	X				X Rope, monkeys	Hunter-gatherer or Forager-trader
Juang, Orissa	X	X	X	X	X	X Basketry, crops	Agriculturalist
Hill Kharia, Orissa	X	X				X Honey, arrowroot	Hunter-gatherer or Forager-trader
Kutia Khond, Orissa	X	X	X	X	X	X Crops	Agriculturalist
Lodha, Orissa	X	X				X Silkworm	Hunter-gatherer or Forager-trader
Paudi Bhuinya, Orissa	X	X	X	X	X	X Crops, fruits	Agriculturalist
Paharia, Rajmahal Hills, Bihar	X	X	X		X	X Tools	Agriculturalist

Figure 3.8: Table of modes of subsistence used by some of the modern tribal groups. The main products that the group's trade is indicated and they are usually traded for rice, alcohol, and clothing. References for the table are Pratap (2000), Mehta (2004), Patnaik (2005).

Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
PAHARIA	Cutting and burning the jungle →			Clearing weeds →				Watching crops →			
					Sowing seeds →				Harvesting →		
Gathering and hunting takes place throughout the year when seasonal wild produce is available											
In hills			Forest clearing and burnt Millets sown		Ploughing & sowing of Podu fields				Some millets harvested		
						Weeding & guarding of fields →				Harvesting of rice, millet, and other hill crops	
BONDO											
Reaping and threshing rice	Prep of seed beds, sowing and transplanting rice		Work in **open and irrigated fields** over by April								

Figure 3.9 – Table shows the year round agricultural scheduling for two tribal groups. Pratap (2000) was the source for information on Paharia and for the Bondo, Kornel (2006) was used.

Site	Dates in BP	Cal. BC date (Oxcal)
Chopani-Mando, Uttar Pradesh BS-129	 4540±110	 3500-3030
Lekhahia, Madhya Pradesh TF-417 (Phase 3) TF-419 (Phase 1)	 3560±105 4240±110	 2120-1730 3010-2620
Sarai-Nahar-Rai, Uttar Pradesh TF-1356 & 1359 TF-1104	 2860±120 10050±110	 1260-890 9950-9300
Mahadaha, Uttar Pradesh BS-137 BS-138 BS-136 OxA 1647	 2880±250 3849±130 4010±120 6320±80	 1400-800 2490-2060 2900-2300 5470-5140

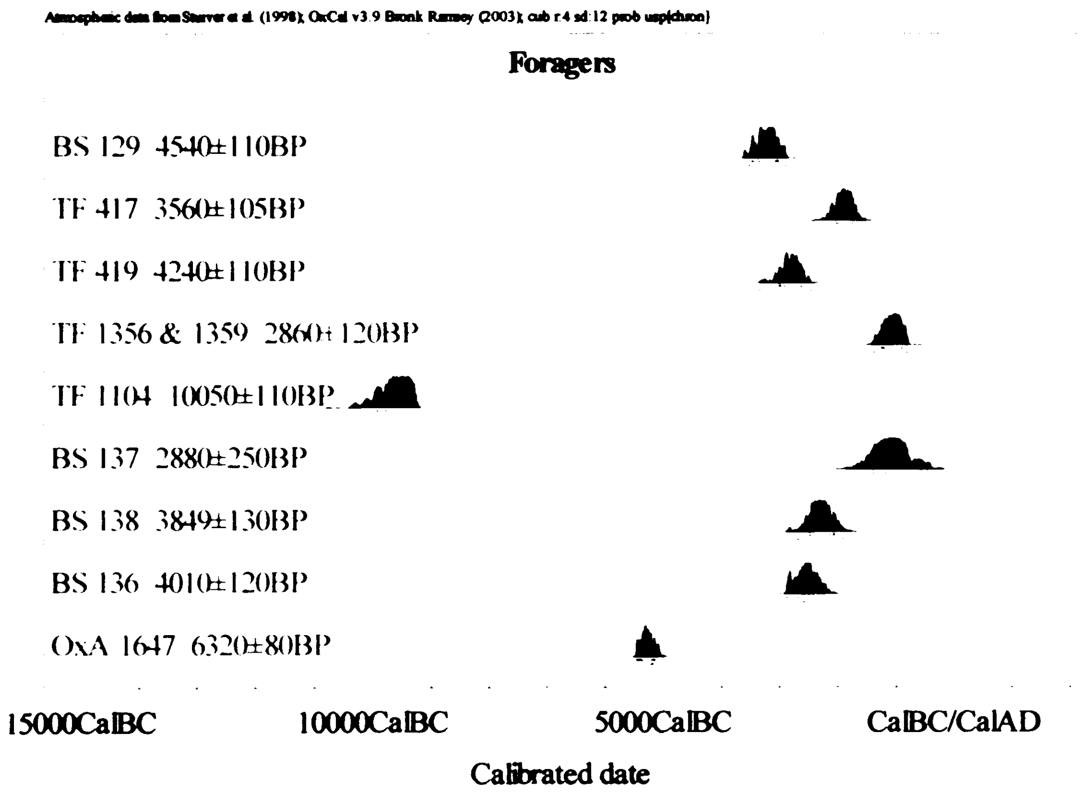


Figure 4.1: Table of published radiocarbon dates and a multiplot for foraging sites in Northern India.

Site	Dates in BP	Cal. BC date (Oxcal)
Koldihwa, Uttar Pradesh		
PRN-223	3300±120	1740-1430
PRN-101 (Charcoal)	6300±180	5480-5050
PRN-100 (Charcoal)	7180±230	6250-5800
Mahagara, Uttar Pradesh		
PRL-408	3190±110	1620-1310
PRL-409	3260±150	1740-1320
PRL-407	3300±100	1690-1450
BS-128	3330±100	1690-1450
Khunjun River face, Uttar Pradesh		
Beta 4879	3120±70	1500-1260
Beta-6414	4010±110	2900-2300
Beta-6415	4600±80	3520-3100
Malhar, Uttar Pradesh		
BS-1614 (Charcoal – Period II)	6380±110	5480-5250
BS-1623 (Period II)	3450±90	2140-1680
BS-1593 (Period II)	3540±90	2300-1700
BS-1590 (Period I)	3850±80	2600-2000
Lahuradewa, Uttar Pradesh		
BS-1951 (Charcoal) (Period IA)	5320±90	4250-4000
BS-1966 (Period IA)	6290±160	5470-5050
BS-1965 (Natural between IA & IB)	4410±140	3550-2600
BS-1950 (Period IB)	3750±90	2500-1900
BS-1938 (Period IB)	3180±70	1620-1290
Narhan, Uttar Pradesh		
BS-850	3040±100	1550-1000
BS-852	3050±100	1550-1000
BS-686	2430±110	850-350
Khairadih, Uttar Pradesh		
CAMS 724	3990±100	2850-2300
PRL-1049		*1190±16*
BS-722		*900±90*
BS-519		*1290±90*
Sohagaura, Uttar Pradesh		
PRL-179	3090±130	1700-950
PRL-178	3190±110	1750-1100

Figure 4.2: Tables of dates and multiplots for early farming settlements in Uttar Pradesh and Bihar. Dates in italics are reported dates in BC that can not be calibrated.

Site	**Dates in BP**	**Cal. BC date (Oxcal)**
Barudih, Bihar – Neolithic Phase		
PRL-188A	2770±140	1400-500
PRL-187	3040±150	1700-850
PRL-15	3290±135	1950-1200
Chirand, Bihar – Chalcolithic		
TF-444	2590±105	950-400
TF-1029	2915±85	1320-890
TF-1028	3390±90	1920-1490
TF-1030	3430±100	2050-1450
TF-445	3500±100	2150-1500
Chirand, Bihar - Neolithic		
TF-1126	2290±120	800-50
TF-1036	2485±120	900-350
TF-334	2715±120	1300-500
TF-1035	3125±100	1700-1050
TF-1127	3230±95	1740-1290
TF-1125	3365±150	2150-1250
TF-1033	3390±110	1950-1400
TF-1034	3420±110	2050-1450
TF-1031	3525±135	2300-1500
TF-1032	3600±150	2500-1500
Senuwar, Bihar		
BS-908 (Layer 16 – IA)	3890±100	2700-2000
BS-911 (Layer 14 – IA)	3540±130	2300-1500
BS-910 (Layer 7 – IB)	2960±80	1400-970
BS-932 (Layer 10 – IB)	3130±140	1750-1000
BS-755 (Layer 7 – IB)	3720±120	2500-1750
BS-757 (Layer 6 – IB)	3450±110	2050-1450
BS-915 (Layer 6 – II)	3160±120	1750-1050
BS-931 (Layer 4 – II)	2650±110	1050-400

Figure 4.2 continued: Tables of dates and multiplots for early farming settlements in Uttar Pradesh and Bihar. Dates for both tables (figures 4.1 & 4.2) are taken from Bellwood et al. 1992, Possehl & Rissman 1992, Chattopadhyaya 1996, Kusumgar & Yadava 2002, and Tewari et al. 2003.

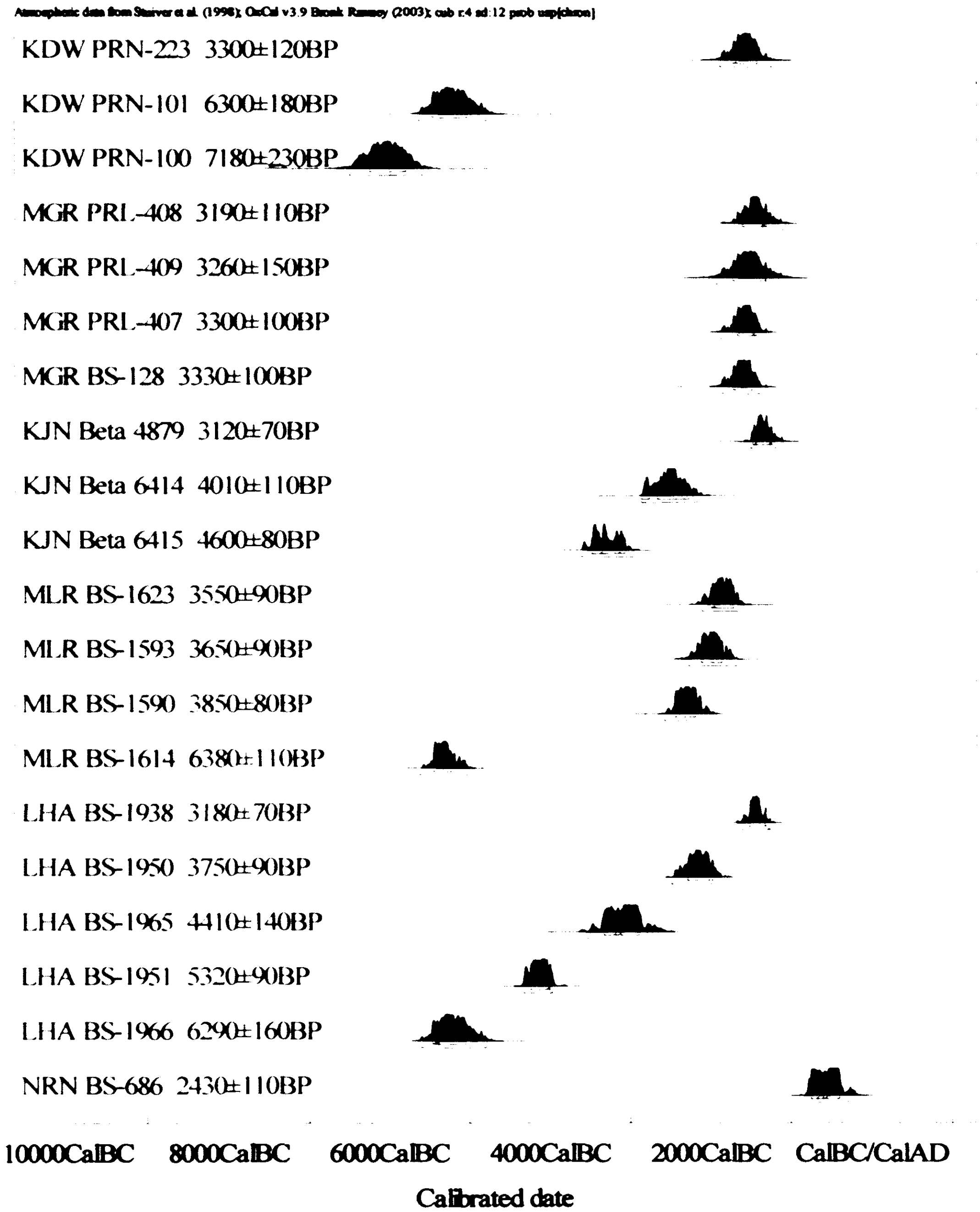


Figure 4.2 continued: Multiplot of available calibrated dates for early farming sites.

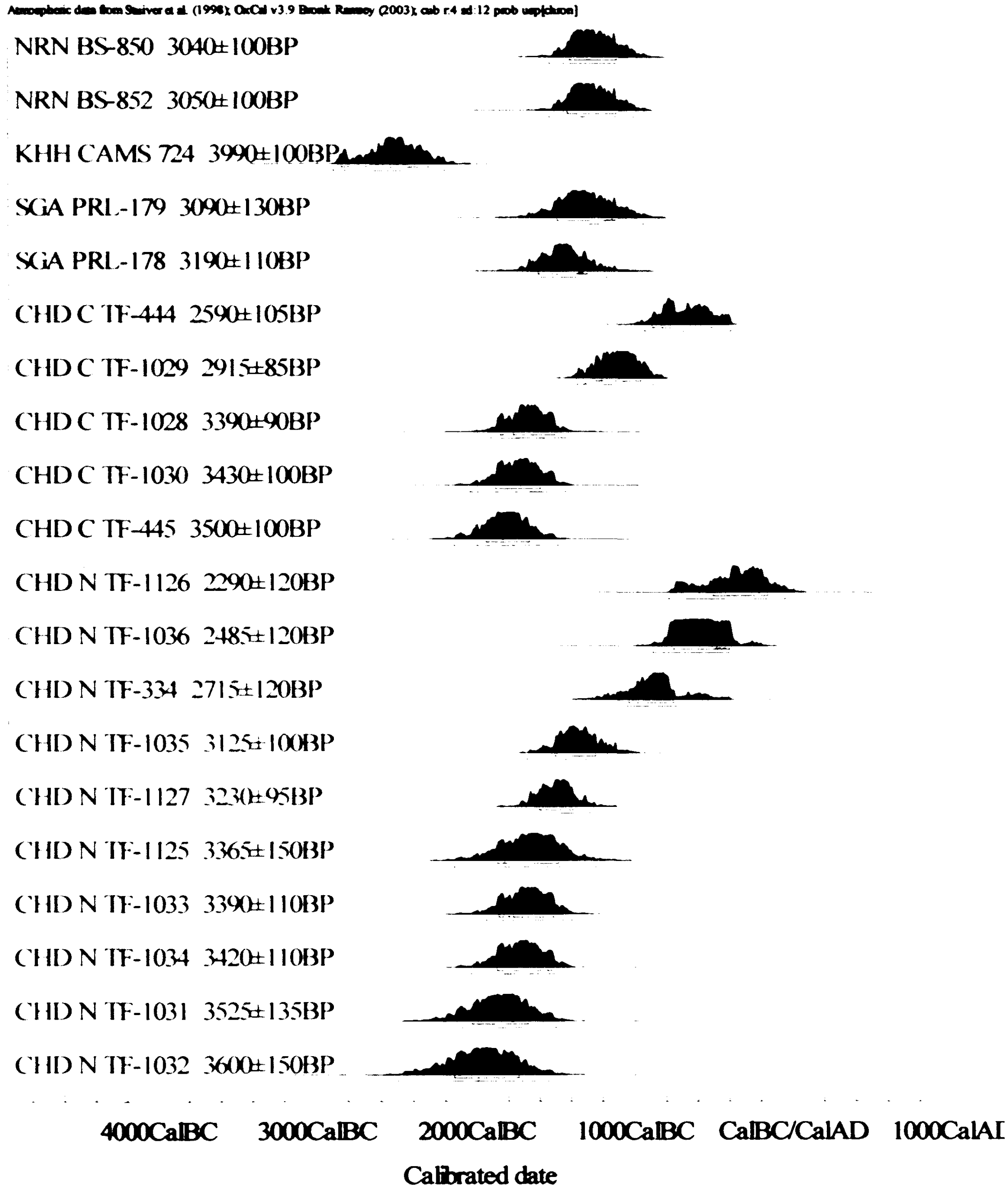


Figure 4.2 continued: Multiplot of available calibrated dates for early farming sites.

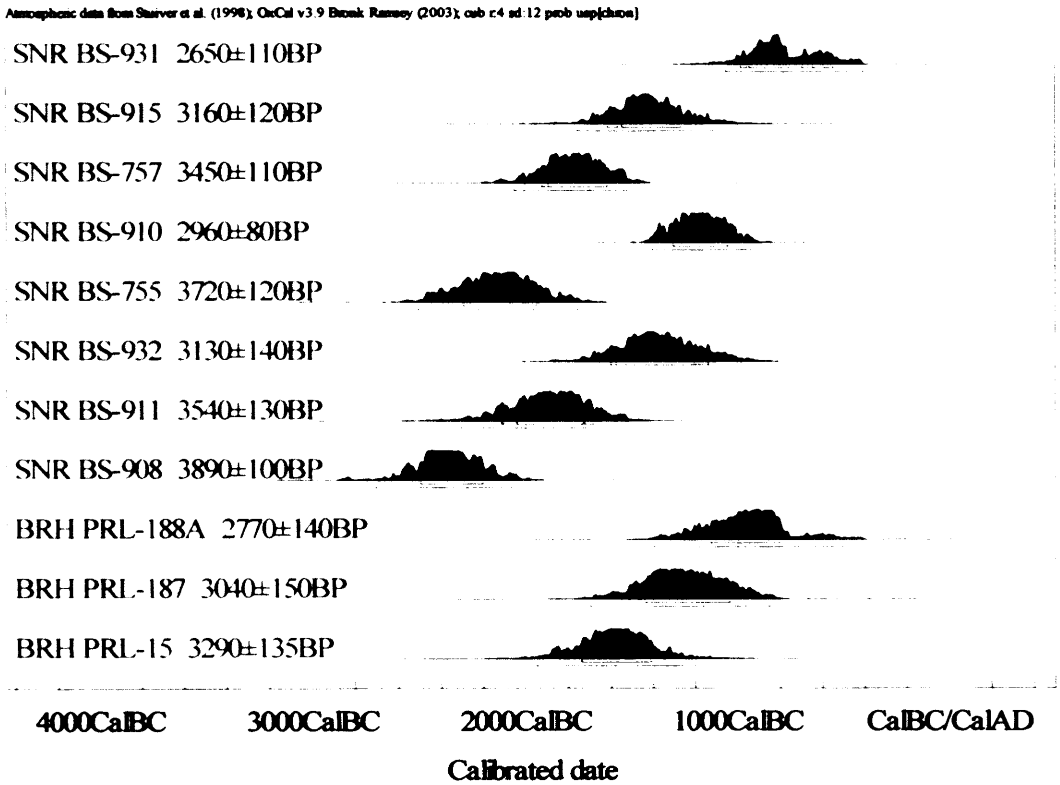


Figure 4.2 continued: Multiplot of available calibrated dates for early farming sites.

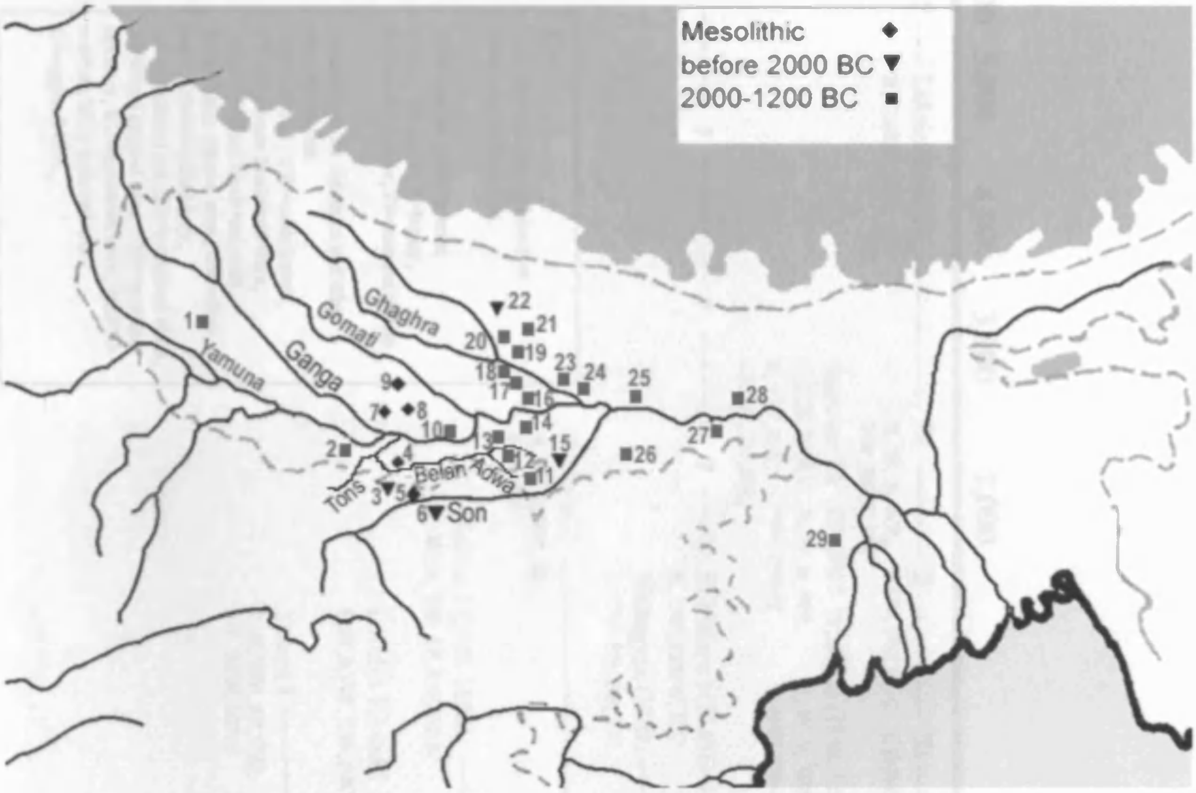


Figure 4.3: Map of the Ganges River Valley showing the important sites mentioned in the text. Key: 1. Atranjikhera; 2. Sringeverapura; 3. Koldihwa & Mahagara; 4. Chopani-Mando; 5. Lekhahia; 6. Khunjhun II; 7. Sara Nahar Rai; 8. Mahadaha; 9. Damdama; 10. Agiabar; 11. RajaNala Ka Tila; 12. Tokwa; 13. Baraunha; 14. Malhar; 15. Senuwar; 16. Waina; 17. Bhunadih; 18. Khairadih; 19. Sohagaura; 20. Imlidih-Khurd; 21. Narhan; 22. Lahuradewa; 23. Manjhi; 24. Chirand; 25. Chechar Kutubpur; 26. Taradih; 27. Oriup; 28. Sungbhum/Barudih; 29. Pandu Rajar Dhibi.

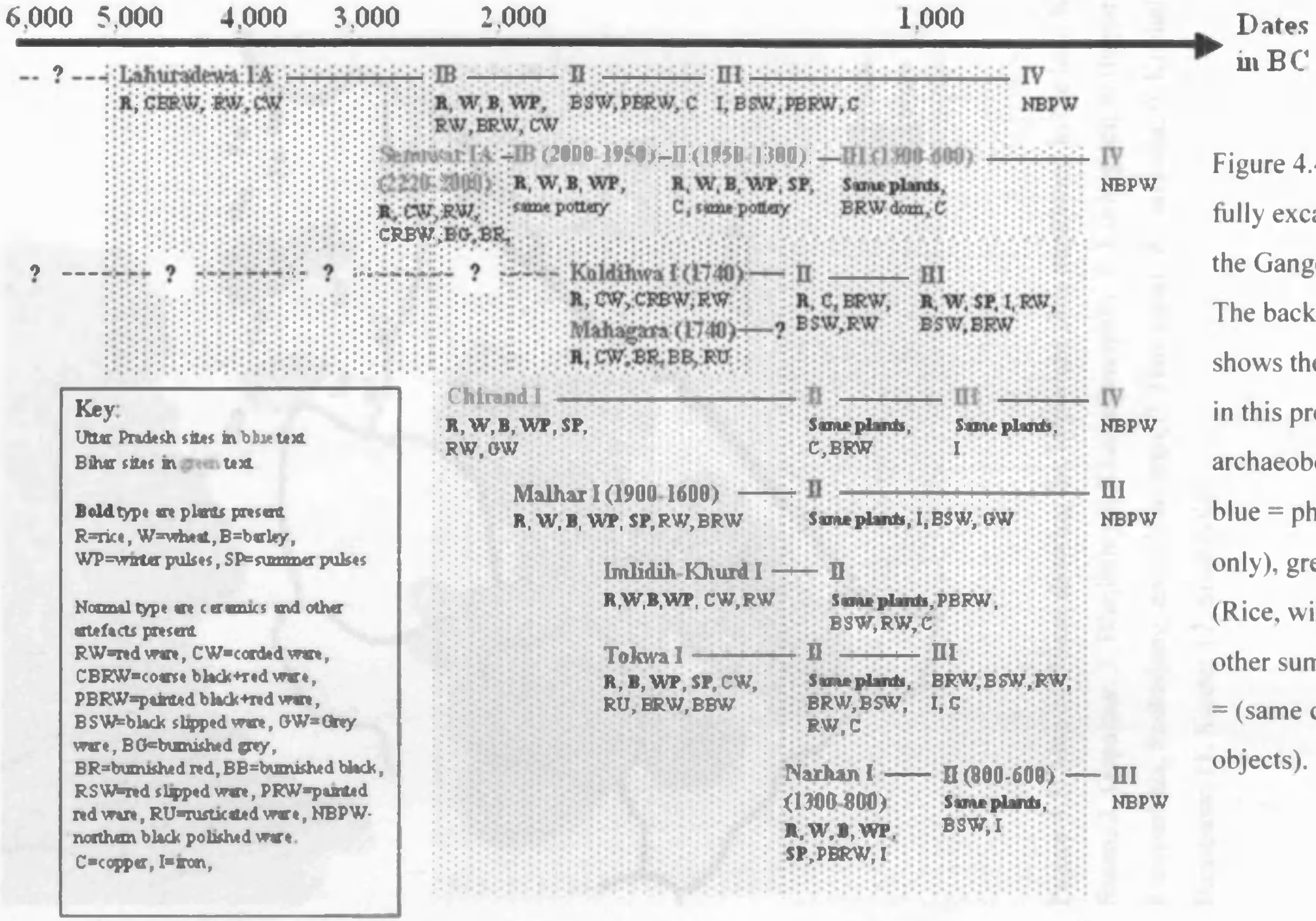


Figure 4.4: Timeline of fully excavated sites from the Ganges River Valley. The background shading shows the phases defined in this project by archaeobotanical finds: blue = phase 1 (Rice only), green = phase 2 (Rice, winter crops, and other summer crops), red = (same crops + copper objects).

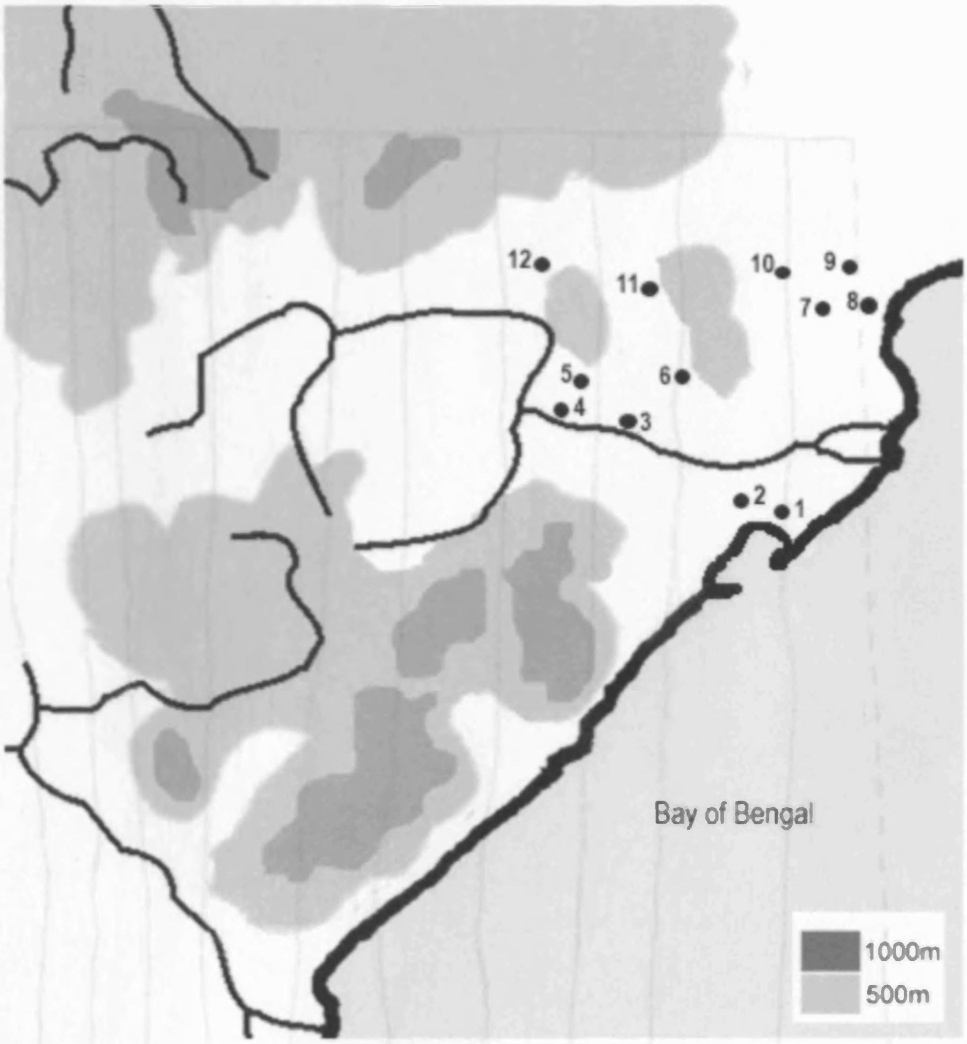


Figure 4.5: Map of Orissa showing the important sites mentioned in the text. Key: 1. Golbai Sasan; 2. Gopalpur; 3. Bhejidihi; 4. Khameswaripalli; 5. Kurmigudi; 6. Bajpur, Kamparkala, Sankerjang, and Malakhoja; 7. Baidyapur; 8. Baghada; 9. Kuchai; 10. Banabasa; 11. Kuanr; 12. Sulabhdihi.

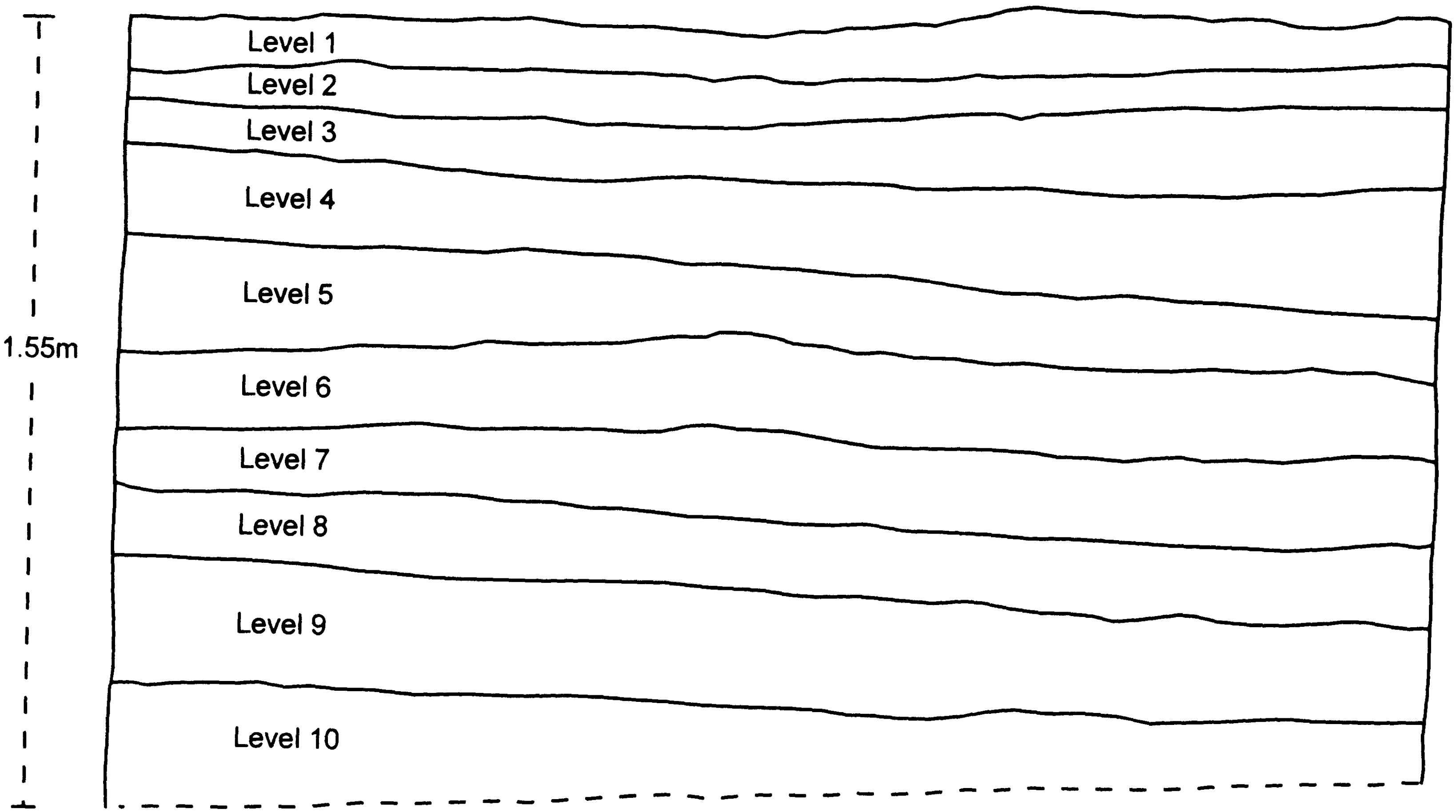


Figure 5.1: Section drawing of Chopani Mando.

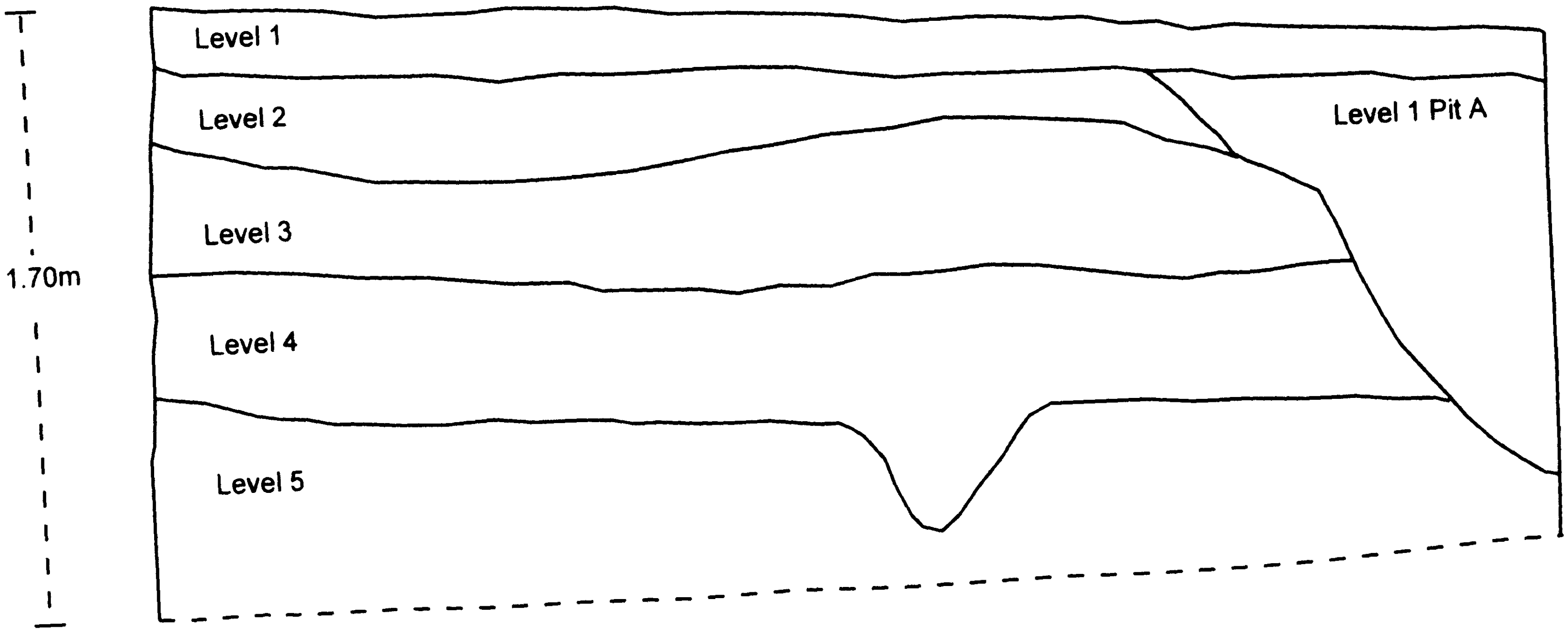


Figure 5.2: Section drawing of Koldihwa.

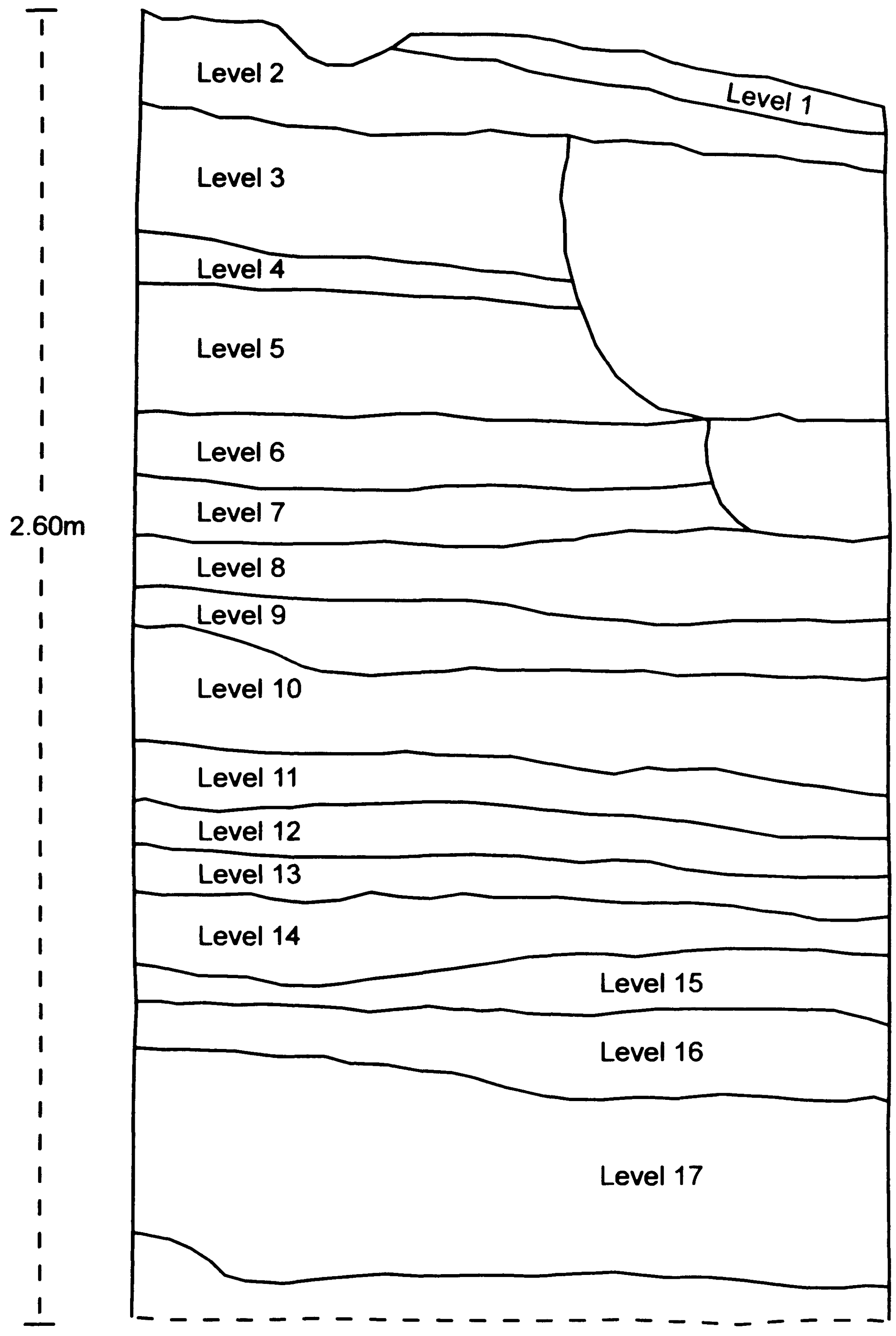


Figure 5.3: Section drawing of Mahagara.

Level number	Macro-botanical sample number	Phytolith sample number	Cultural Phase
1	ABOT 53 & 54	1	Advanced Mesolithic
2	ABOT 55 & 56	-	Advanced Mesolithic
3	ABOT 57 & 58	3	Advanced Mesolithic
4	ABOT 59 & 60	-	Early Mesolithic Geometric
5	ABOT 61 & 62	5	Early Mesolithic Geometric
6	ABOT 63 & 64	-	Early Mesolithic Geometric
7	ABOT 65 & 66	7	Early Mesolithic Geometric
8	ABOT 67 & 68	-	Early Mesolithic Non-geometric
9	ABOT 69 & 70	9	Early Mesolithic Non-geometric
10	ABOT 71 & 72	-	Epi-Palaeolithic

Figure 5.4: Table explaining where samples come from in the Chopani-Mando section.

Level number	Macro-botanical sample number	Phytolith sample number	Cultural Phase
Z1-1	ABOT 1 & 2	1	Chalcolithic/ Iron Age
Z1-1 – Pit	-	2	Chalcolithic/ Iron Age
Z1-2	ABOT 3 & 4	3	Chalcolithic
Z1-3	ABOT 5 & 6	4	Neolithic
Z1-4	ABOT 7 & 8	5	Neolithic
Z1-5	ABOT 9 & 10	6	Sterile
Y1-1	ABOT 11 & 12	7	Chalcolithic/ Iron Age
Y1-2	ABOT 13 & 4	8	Chalcolithic
Y1-3	ABOT 15 & 16	9	Neolithic
Y1-4	ABOT 17 & 18	10	Neolithic
Y1- 5	ABOT 19 & 20	11	Sterile

Figure 5.5 continued: Table explaining where sample come from in the Koldihwa Z1 & Y1 section.

Site	**Dates in BP**	**Cal. BC date (Oxcal)**
Koldihwa, Uttar Pradesh		
OxA-14096 (ABOT 2 – layer Z1 1 - Rice)	2476 ± 27	765-480
OxA-14097 (ABOT 2 – layer Z1 1 - Barley)	2546 ± 29	805-755
OxA-14098 (ABOT 4 – layer Z1 2 - Rice)	2466 ± 29	765-605
OxA-14127 (ABOT 17 – layer Y1 4 - Barley)	3460 ± 30	1880-1835
OxA-14159 (ABOT 8 – layer Z1 4 – Rice)	2656 ± 28	1395-1210
Mahagara, Uttar Pradesh		
OxA-14092 (ABOT 39 – layer 11 - Rice)	3238 ± 29	1545-1430
OxA-14094 (ABOT 50 – layer 16 - Barley)	3269 ± 29	1625-1485
OxA-14095 (ABOT 50 – layer 16 - Lentil)	3321 ± 29	1685-1520
OxA-14158 (ABOT 49 – layer 16 –*V.radiata*)	3270 ± 29	1625-1485

Figure 5.6: New dates from new archaeobotanical remains from Belan River Valley.

Level number	**Macro-botanical sample number**	**Phytolith sample number**	**Cultural Phase**
1	-	10	Topsoil/Neolithic
2	ABOT 21 & 22	-	Neolithic
3	ABOT 23 & 24	9	Neolithic
4	ABOT 25 & 26	-	Neolithic
5	ABOT 27 & 28	8	Neolithic
6	ABOT 29 & 30	-	Neolithic
7	ABOT 31 & 32	7	Neolithic
8	ABOT 33 & 34	-	Neolithic
9	ABOT 35 & 36	6	Neolithic
10	ABOT 37 & 38	-	Neolithic
11	ABOT 39 & 40	5	Neolithic
12	ABOT 41 & 42	4	Neolithic
13	ABOT 43 & 44	3	Neolithic
14	ABOT 45 & 46	-	Neolithic
15	ABOT 47 & 48	2	Neolithic
16	ABOT 49 & 50	-	Neolithic
17	ABOT 51 & 52	1	Neolithic

Figure 5.7: Table explaining where samples come from in the Mahagara section.

Figure 5.8: Section photograph of Gopalpur.

Figure 5.9: Section photograph of Golbai Sasan.

Figure 5.10: Photograph of Bajpur.

Figure 5.11: Photograph of Banabasa.

Figure 5.12: Photograph of section at Malakhoja.

Layer number	Layer description	Flot number	Phytolith number
1	Topsoil – yellow/brown clay, 7.5YR 5/3 Archaeological artefacts present but disturbed layer	None	1 sample
2	Red laterite sand	None	None
3	Archaeological level – yellow/brown darker than 1 – clay	1 sample x 20L	1 sample
4	Red laterite	None	None
4A	Fine grey sand – very thin layer	None	None
6	Red laterite	None	None
5	Above layer 7A	1 sample x 20L	1 sample
7A	Thin black layer on top of layer 7B	1 sample x 20L	1 sample
7B	Yellow/light brown sandy clay	1 sample x 20L	1 sample
8	Grey clay	1 sample x 20L	1 sample
9	Dark grey clay	1 sample x 20L	1 sample
10	Dark red/brown sandy clay	1 sample x 20L	1 sample
11	Light yellow brown clay	1 sample x 20L	1 sample
12	Dark red/brown clay mottled with charcoal flecking	1 sample x 20L	1 sample
13	Light yellow brown	4 samples x 20L A, B, C, D	4 samples A, B, C, D
14	Grey clay – pit with charcoal	3 samples x 20L A, B, C	3 samples A, B, C

Figure 5.13: Table of the soil descriptions from Golbai Sasan sampled section.

Site	Dates in BP	Cal. BC date (Oxcal)
Golbai Sasan, Orissa		
OxA-14132 (layer 3 - Rice)	2927 ± 28	1215-1010
OxA-14133 (layer 9 - Rice)	2943 ± 28	1220-1040
OxA-14134 (layer 13D - Rice)	2966 ± 32	1265-1050
OxA-14135 (layer 13D – *V. radiata*)	2920 ± 29	1215-1005
Gopalpur, Orissa		
OxA-14128 (layer 2 - Pigeonpea)	3035 ± 31	1395-1210
OxA-14129 (layer 6 - Rice)	2964 ± 30	1365-1045
OxA-14130 (layer 8 - Rice)	2983 ± 32	1320-1110
OxA-14131 (layer 13 – Rice)	2874 ± 45	1170-915

Figure 5.14: New dates from new archaeobotanical remains from Orissa.

Flot sample number	Phytolith sample number	Level depth
None	None	30-40 cm of soil above top sample but it is disturbed due to ploughing
GPR-03A-15	Phyto 15	395 cm
GPR-03A-14	Phyto 14	365 cm
GPR-03A-13	Phyto 13	335 cm
GPR-03A-12	Phyto 12	295 cm
GPR-03A-11	Phyto 11	270 cm
GPR-03A-10	Phyto 10	250 cm
GPR-03A-9	Phyto 9	205 cm
GPR-03A-8	Phyto 8	180 cm
GPR-03A-7	Phyto 7	145 cm
GPR-03A-6	Phyto 6	115 cm
GPR-03A-5	Phyto 5	95 cm
GPR-03A-4	Phyto 4	78 cm
GPR-03A-3	Phyto 3	60 cm
GPR-03A-2	Phyto 2	40 cm
GPR-03A-1	Phyto 1	20 cm
None	None	0cm at bottom of section

Figure 5.15: Table of samples taken at Gopalpur.

Flot sample number	Phytolith samples number	Level depth	Notes
MKA-03A-1	Phyto 1	0 – 40 cm top	Topsoil – coarse red ware pottery
MKA-03A-2	None	0 – 40 cm bottom	Topsoil – coarse red ware pottery and red and black ware
MKA-03A-3	None	40 – 80 cm top	Archaeological
MKA-03A-4	Phyto 4	40 – 80 cm middle	Archaeological
MKA-03A-5	None	40 – 80 cm bottom	Archaeological
MKA-03A-6	None	80 – 110 cm top	Archaeological
MKA-03A-7	Phyto 7	80 – 110 cm middle	Archaeological
MKA-03A-8	None	80 – 110 cm bottom	Archaeological
MKA-03A-9	Phyto 9	110 – 140 cm top	Natural
MKA-03A-10	None	110 – 140 cm bottom	Natural

Figure 5.16: Table of samples taken at Malakhoja. Finds were only found in the top two samples.

Flot sample number	Phytolith samples number	Level depth	Notes
None	Phyto 0	0-10 cm	Topsoil
BJR-03A-1	Phyto 1	10-20 cm	Neolithic
BJR-03A-2	Phyto 2	20-30 cm	Neolithic
BJR-03A-3	Phyto 3	30-40 cm	Neolithic
BJR-03A-4	Phyto 4	40-50 cm	Mesolithic

Figure 5.17: Table of samples taken at Bajpur.

Flot sample number	Phytolith samples number	Level depth
None	Phyto 0	0-10 cm
BNA-03A-1	Phyto 1	10-20 cm
BNA-03A-2	Phyto 2	20-30 cm
BNA-03A-3	Phyto 3	30-40 cm

Figure 5.18: Table of samples taken from Banabasa.

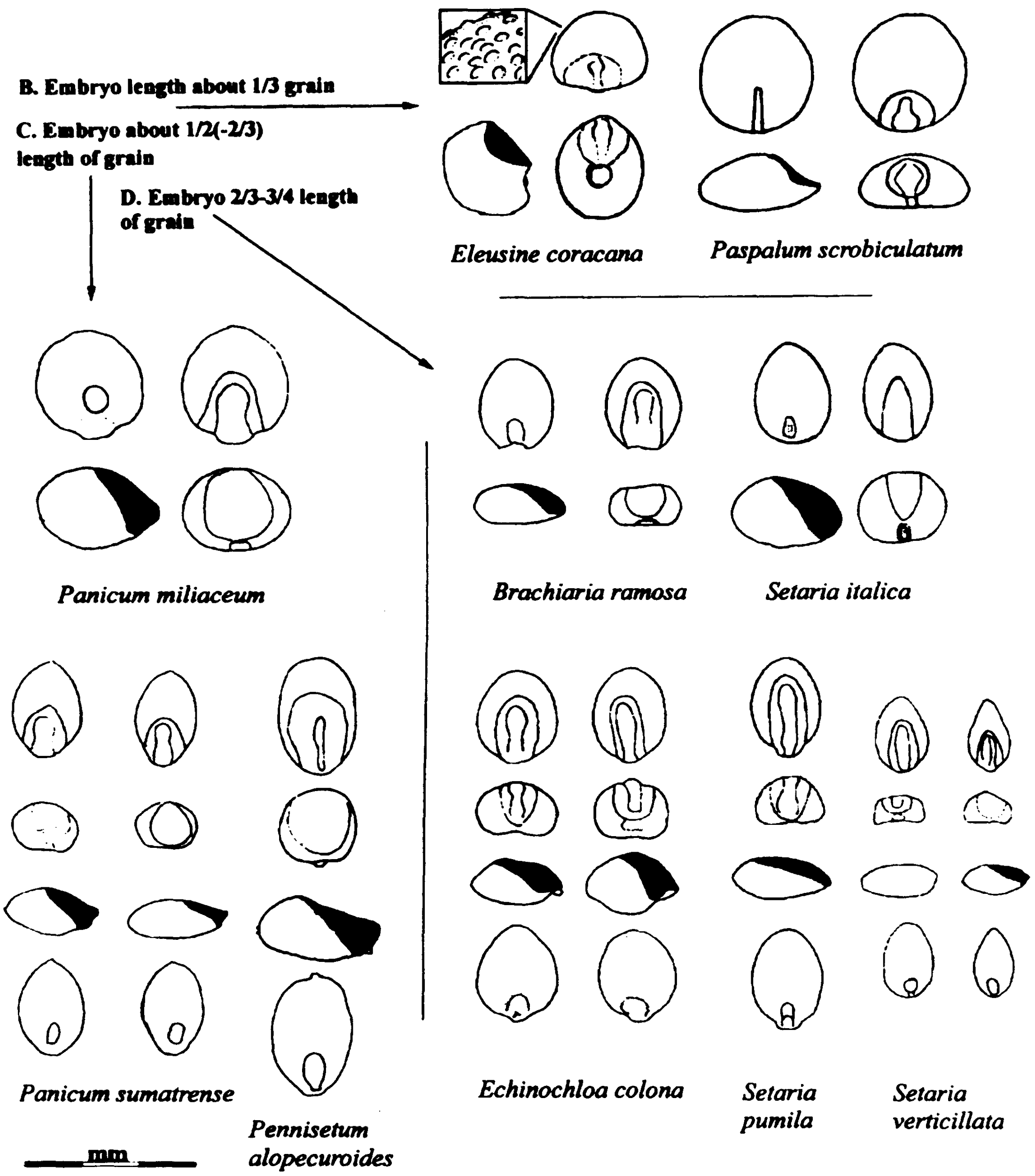


Figure 5.19: Identification key for small millets using embryo length to overall length of grain (after Fuller 1999, fig. 6.8).

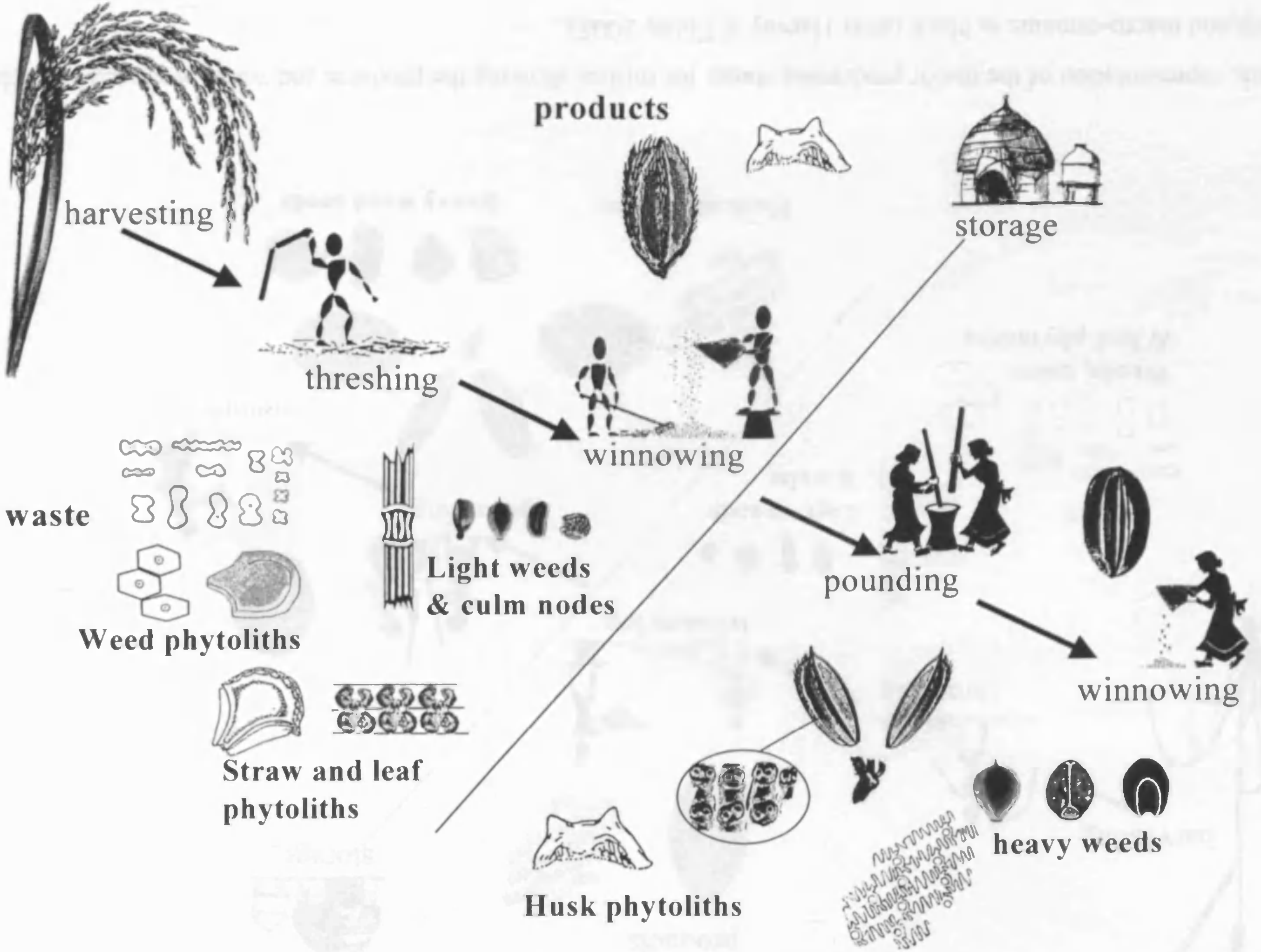


Figure 5.20: Schematic representation of the major processing stages for rice showing the products and waste produced by each process. Phytoliths are in white and macro-remains in black. For example, first winnowing produces grains with spikelets and therefore husk phytoliths, and the waste contains rice leaves and stem (fan-shaped bulliforms and scooped rice bilobes) and various weeds associated with rice cultivation such as grasses (bilobes shown, also saddles, long cells), sedges, and phragmites (keystone bulliform). After dehusking the waste of winnowing includes husks as well as large weeds, which also may be removed by hand picking (after Harvey & Fuller 2005).

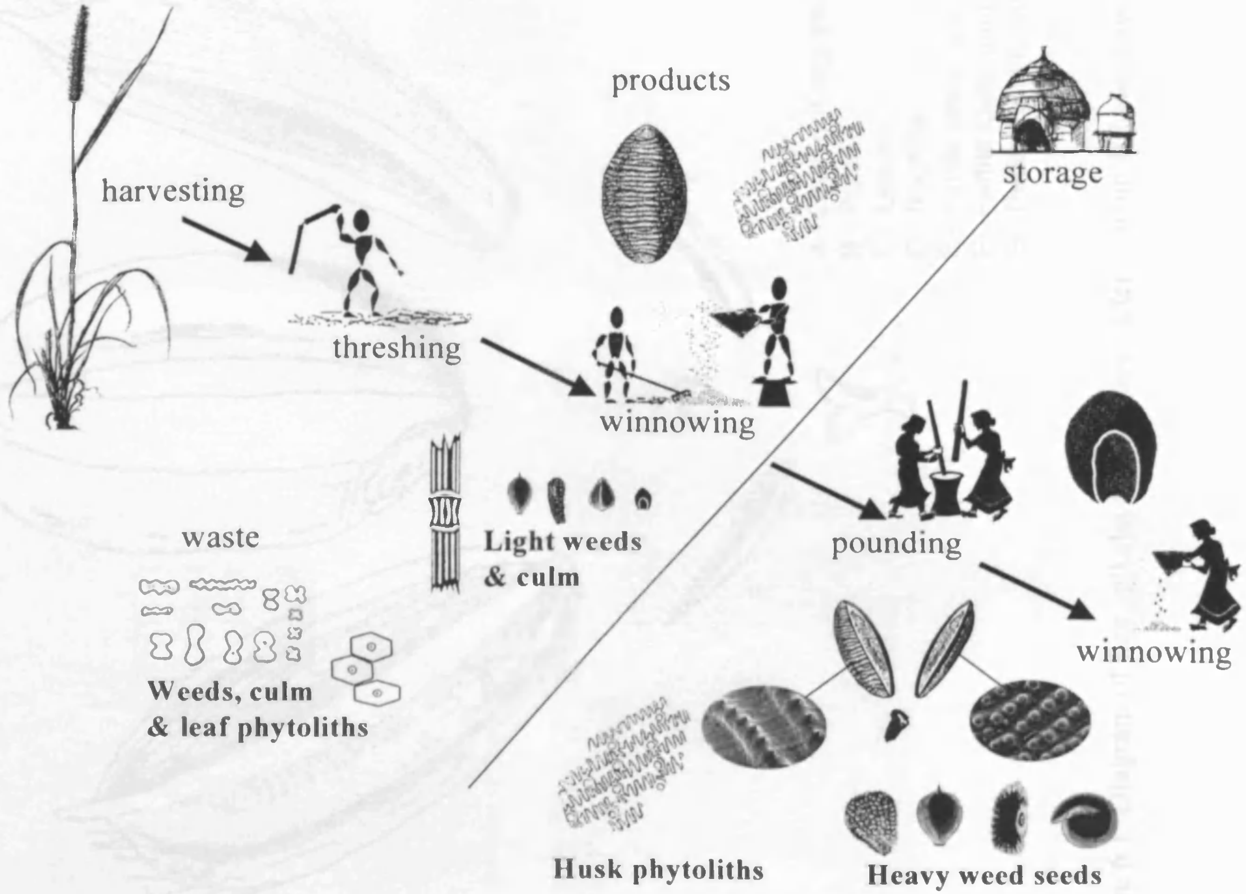


Figure 5.21: Schematic representation of the major processing stages for millets showing the products and waste produced by each process. Phytoliths are in white and macro-remains in black (after Harvey & Fuller 2005).

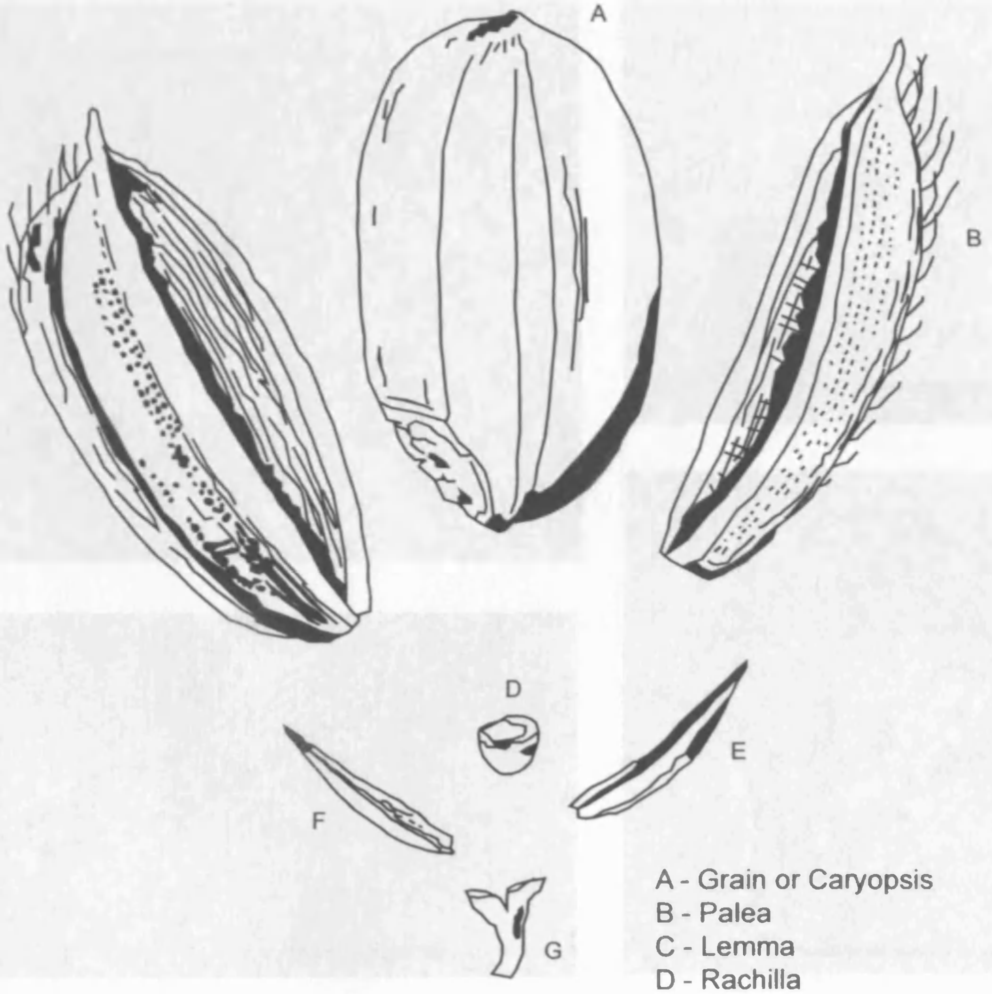


Figure 6.1: Diagram of rice spikelet terminology (after Matsuo & Hoshikawa 1993).

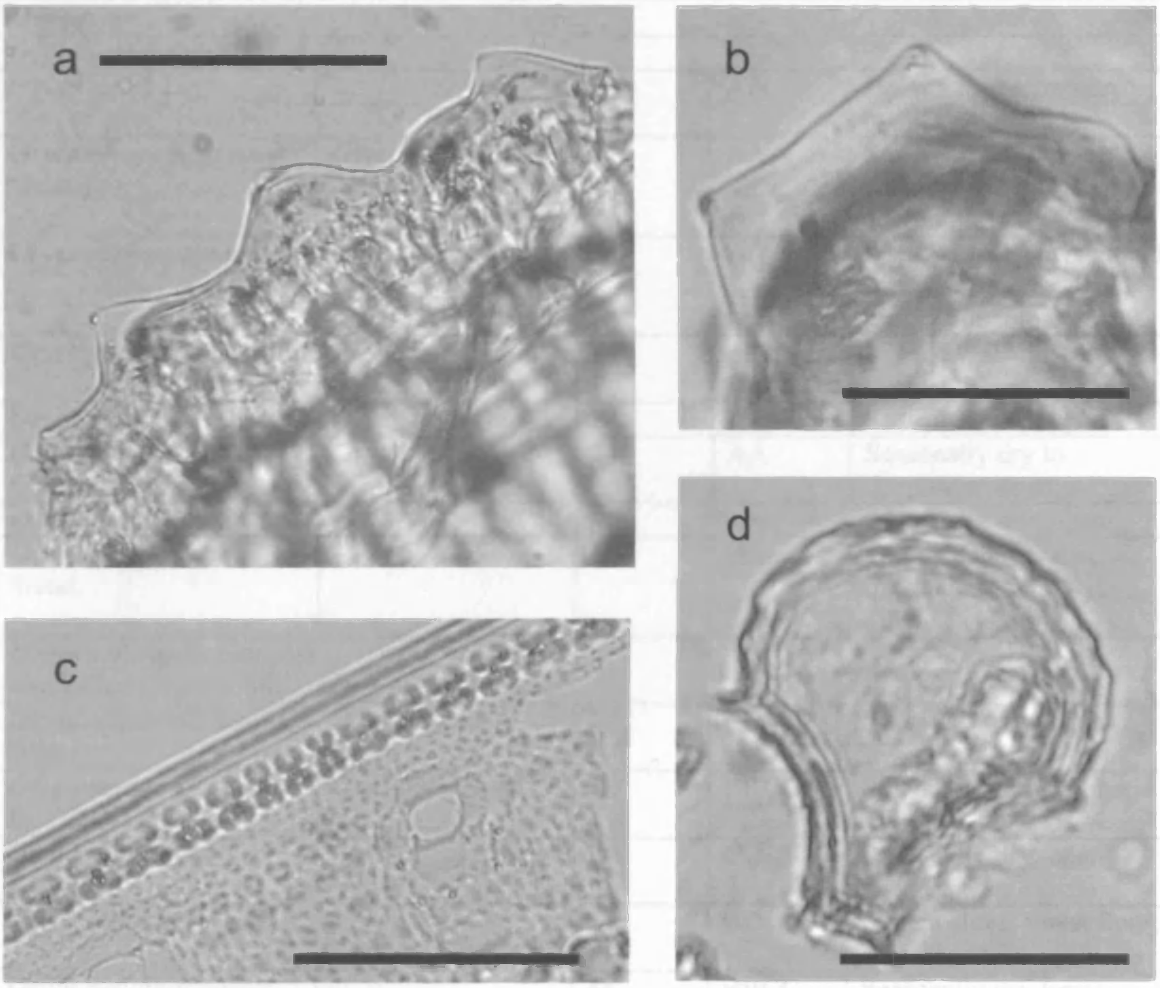


Figure 6.2: Photographs of the different rice phytoliths. (a) Rice husk multi-cell panel; (b) double-peaked husk cell; (c) scooped bilobes from the rice leaf; (d) fan-shaped bulliform from the rice leaf. Scale bar = 20μm.

Complex **Species**	**Other name(s) commonly found in literature**	**Chromo some number**	**Genome group**	**Usual habitat; Uses**
Oryza				
Oryza sativa **complex**				
Oryza sativa L.	-	24	AA	Upland to Deepwater; open; cultigen
Oryza nivara Sharma et Shastry	*Oryza rufipogon* (annual form)	24	AA	Seasonally dry; open; eaten by tribals, Bhramins and poor
Oryza ruripogon Griff.	*Oryza perennis, Oryza rufipogon* (perennial form)	24	AA	Seasonally deepwater and wet year round; open; grains sometimes eaten
Oryza glaberrima Steud.	-	24	AA	Upland to deepwater; open; cultigen
Oryza barthii A. Chev.	O.breviligulata	24	AA	Seasonally dry; open
Oryza longistaminata Chev. Et Roehr.	Oryza barthii	24	AA	Seasonally dry to deepwater; open
O.meridionalis Ng	-	24	AA	Seasonally dry; open
Oryza glumaepatula Steud.	-	24	AA	Inundated areas that become seasonally dry; open
Oryza officinalis **complex** also called *Oryza latifolia* complex or group				
Oryza officinalis Wall ex Watt	*Oryza minuta*	24	CC	Seasonally dry; open
Oryza minuta JS Presl. Ex CB Presl.	*Oryza officinalis*	48	BBCC	Stream sides; semi shade
Oryza rhizomatis Vaughan	-	24	CC	Seasonally dry; open
Oryza eichingeri Peter	-	24	CC	Stream sides; forest floor; semi shade
Oryza malapuzhaensis Krishnaswamy and Chandrasakaran	-	48	BBCC	Seasoanlly dry forest pools; shade
Oryza punctata Kotschy ex Streud.	*Oryza schweinfurthiana* for tetraploid form	24 48	BB, BBCC	Diplod – seasonally dry; open Tetraploid – forest floor; shade
Oryza latifolia Desv.	-	48	CCDD	Seasonally dry; open
Oryza alta Swallen	-	48	CCDD	Seasonally inundated; open
Oryza grandiglumis (Doell.) Prod.	-	48	CCDD	Seasonally inundated; open
Oryza australiensis Domin	-	24	EE	Seasonally dry; open

Figure 6.3: A table of the *Oryza* taxonomic classifications.

Complex Species	**Other name(s) commonly found in literature**	**Chromo some number**	**Genome group**	**Usual habitat; Uses**
Ridleyanae Tateoka				
Oryza schlechteri Pilger	-	48	-	River banks; open
***Oryza ridleyi* complex**				
Oryza ridleyi Hook.	-	48	HHJJ	Seasonally inundated forest floor; shade
Oryza longiglumis Jansen	-	48	HHJJ	Seasonally inundated forest floor; shade
Granulata Roschev.				
***Oryza granulata* complex**				
Oryza granulata Nees et Am ex Watt	-	24	GG	Forest floor; shade
Oryza meyeriana (Zoll. Et Mor. Ex Streud.) Baill.	-	24	GG	Forest floor; shade
Brachyantha B.R. Lu				
Oryza brachyantha Chev. Et Roehr.	-	24	FF	Rock pools; open

Figure 6.3 continued: A table of the *Oryza* taxonomic classifications.

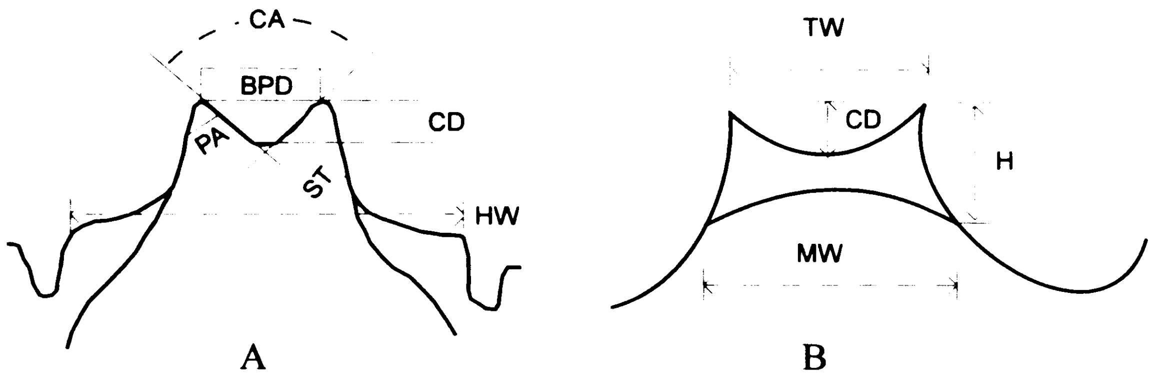


Figure 6.4: Diagram showing the Zhang (2002) (A) and Zhao et al. (1998) (B) method of measuring rice hairs and double-peaked rice husk phytoliths (after Zhang 2002, fig. 2 and Zhao et al. 1998, fig. 2).

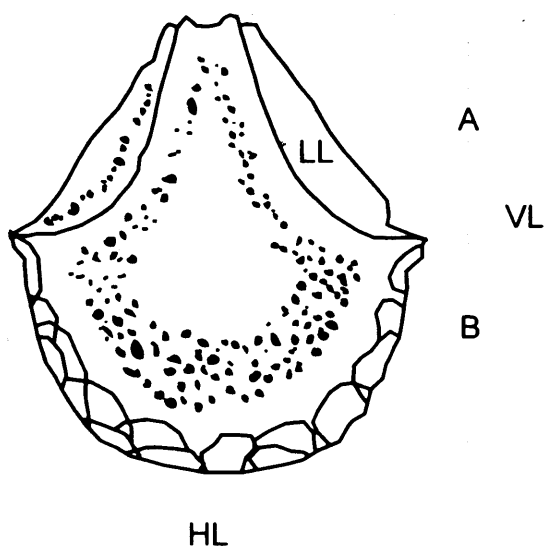


Figure 6.5: Diagram of Fujiwara bulliform measurements (after Fujiwara et al. 1993).

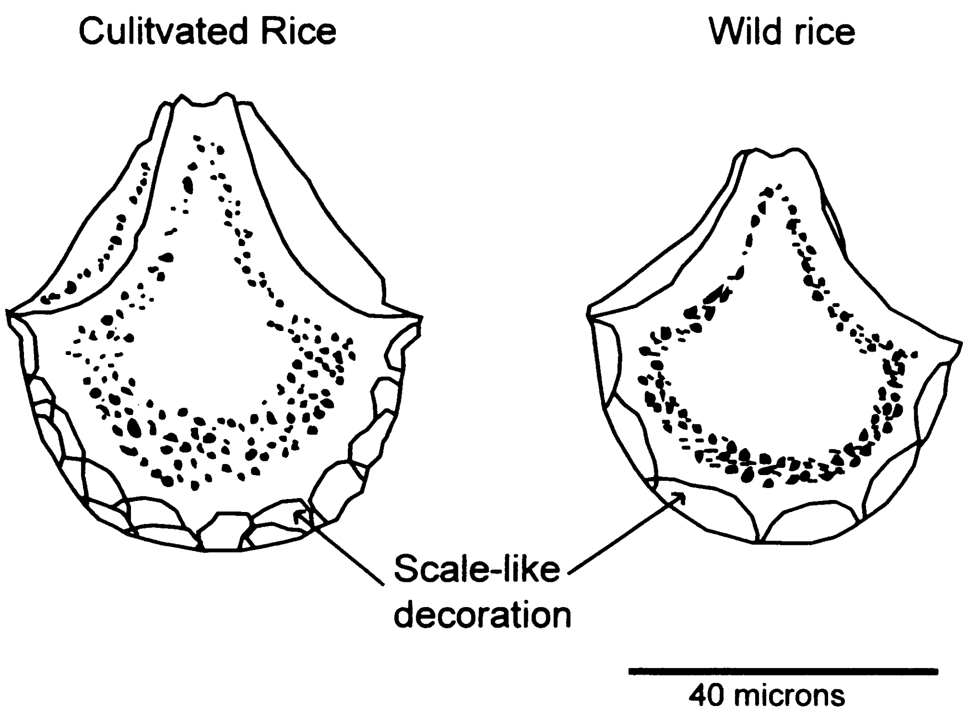


Figure 6.6: Diagram of bulliforms chips of wild and domestic rice (after Lu et al. 2002, fig.3).

Species	Sample numbers	Number of populations
O.sativa	75-87	13
O.nivara	4,7,9,10,11,13,14,15,16,20,21,22,24,25,26,28- 42, 62,63,66,67,68, 70,71,72,	38
O.rufipogon	3,8,18,19,23,43-51,65,	15
O.spontanea	5,17,53,	3
O.officinalis	27,64	2
O.granulata	54,73,74	3
O.punctata	55	1
O.nivara x *O.spontanea*	1,2,	2
O.nivara x *O.rufipogon*	6,57,61	3
O.nivara x *rufipogon* x *spontanea*	12	1
O.rufipogon x *O.spontanea*	52	1
O.nivara x *O.sativa*	56,69	2
O.rufipogon x *O.sativa*	58,59,60	3
Total number of samples	87	87

Figure 6.7: Table showing the number of populations per rice species measured in this project.

Sample No	AccNo IRRI or USDA	Species	Donor Country	Variety name	District	Town	Village	Latitude	Longi tude	Elevati on
1	80436	*O.nivara & spontanea*	India	Kapni	Bastar	-	Tankwade	-	-	-
2	80532	*O.nivara & spontanea*	India	-	Bastar	4KM from Geeham	-	-	-	-
3	80538	*O.rufipogon*	India	Tatangi	Bastar	Jagdalpur	-	19°5'N	82°0'E	-
4	80548	*O.nivara*	India	-	Bastar	Kondagaon	Palari	19°40'N	81°40'E	-
5	80555	*O.spontanea*	India	-	Bastar	Makri	Belgaon	19°49'N	81°55'E	-
6	80556	*O.nivara & rufipogon*	India	-	Bastar	Kondagaon	Sargaon	19°40'N	81°38'E	-
7	80560	*O.nivara*	India	-	Bastar	Narainpur	Nelwao	19°45'N	81°20'E	-
8	80562	*O.rufipogon*	India	-	Bastar	Narainpur	Deogaon	19°45'N	81°19'E	-
9	80573	*O.nivara*	India	-	Bastar	Antagarh	Bhaingaon	19°50'N	81°14'E	-
10	80589	*O.nivara*	India	Pashahar	Bastar	Pakhanjoor	Chindpara	20°10'N	80°45'E	-
11	80593	*O.nivara*	India	-	Bastar	Bhanupratappu r	Kurri	20°20'N	81°10'E	-
12	80594	*O.nivara x rufipogon x spontanea*	India	-	Bastar	Kanker	Bewarati	-	-	-
13	80599	*O.nivara*	India	-	Bastar	Kanker	Atorgaon	20°10'N	81°28'E	-
14	80611	*O.nivara*	India	-	Koraput	Navrangpur	Navrangpur	19°10'N	82°35'E	-
15	80613	*O.nivara*	India	Jharha	Kalahandi	Jaipatana	Ampani	19°34'N	82°40'E	-
16	80621	*O.nivara*	India	-	Raipur	Khariyar road	Temari	20°55'N	82°30'E	-
17	80626	*O.spontanea*	India	Karaga	Raipur	Mahasamund	Mahasamund	21°0'N	82°5'E	-
18	80629	*O.rufipogon*	India	Pasahar	Raipur	Arang	Arang	21°12'N	81°55'E	-
19	80636	*O.rufipogon*	India	Karaga	Raipur	Kasadole	Lavan	21°38'N	82°25'E	-
20	80637	*O.nivara*	India	-	Raipur	Kasadole	Kasadole	21°38'N	82°25'E	-
21	80645	*O.nivara*	India	-	Bilaspur	Takhatpur	Chatona	22°2'N	81°55'E	-
22	80677	*O.nivara*	India	-	Durg	Bhilai	Newai	21°8'N	81°20'E	-

Figure 6.8: List of populations and information of origin.

Sample No	AccNo IRRI or USDA	Species	Donor Country	Variety name	District	Town	Village	Latitude	Longi tude	Elevati on
23	80680	*O.rufipogon*	India	-	Durg	Patan	Tarra	21°8'N	81°34'E	-
24	80695	*O.nivara*	India	Pasahra	Sioni	Barghat	Barghat	-	-	-
25	80697	*O.nivara*	India	Sadla	Mandla	Mandla	Lalipur	-	-	-
26	80703	*O.nivara*	India	Pashera	Balaghat	Gaeshi	Gaeshi	-	-	-
27	80764	*O.officinalis*	India	-	-	-	-	-	-	-
28	81814	*O.nivara*	India	-	Sonbhadra	-	Baghanalamore	-	-	-
29	81815	*O.nivara*	India	-	Mirjapur	-	Lusha Rajgarh	-	-	-
30	81816	*O.nivara*	India	-	Allahabad	-	Bhauntar/Khaga	-	-	-
31	81817	*O.nivara*	India	-	Fatehpur	-	Allayapur/Tiliani	-	-	-
32	81818	*O.nivara*	India	-	Kanpur	-	Uttaripura/Billae	-	-	-
33	81820	*O.nivara*	India	-	Badaun	-	Sanjanpur/mian	-	-	-
34	81821	*O.nivara*	India	-	Bareilly	-	Nagariagtan/Mirg anj	-	-	-
35	81822	*O.nivara*	India	-	Lucknow	-	Kalli/Mollarganj	-	-	-
36	81825	*O.nivara*	India	-	Rai Bareilly	-	Faturiak Purwa/Jabia	-	-	-
37	81826	*O.nivara*	India	-	Sultanpur	-	Bhade/Dubeypr	-	-	-

Figure 6.8 continued: List of populations and information of origin.

Sample No	AccNo IRRI or USDA	Species	Donor Country	Variety name	District	Town	Village	Latitude	Longi tude	Elevati on
38	81827	*O.nivara*	India	-	Pratapgarh	-	Patti	-	-	-
39	81829	*O.nivara*	India	-	Azamgarh	-	Mandejafarpur	-	-	-
40	81830	*O.nivara*	India	-	Varanasi	-	Burhani/Burhani	-	-	-
41	81834	*O.nivara*	India	-	Bhojpur	Piro	Dhanpura	25°15'N	84°20'E	-
42	81839	*O.nivara*	India	-	Jaunpur	Dhobhi	Anandnagar B	25°30'N	83°'E	-
43	81877	*O.rufipogon*	India	-	Sonbhadra	-	Devra/Robertsganj	-	-	-
44	81878	*O.rufipogon*	India	-	Sidauli	-	Kuchora Bangla	-	-	-
45	81879	*O.rufipogon*	India	-	Lucknow	-	Kalli/Mollarganj	-	-	-
46	81880	*O.rufipogon*	India	-	Faizabad	-	Ranapur/Sahebganj	-	-	-
47	81885	*O.rufipogon*	India	-	Gorakhpur	Bhatthat	Bhatthat	26°50'N	83°32'E	-
48	81888	*O.rufipogon*	India	-	Maharaganj	Prenda	Sonversha	27°'N	83°15'E	-
49	81896	*O.rufipogon*	India	-	Gonda	Nagwa	Dumeriadi	26°55'N	82°5'E	-
50	81897	*O.rufipogon*	India	-	Faizabad	Pura	Roshannagar	26°43'N	82°20'E	-
51	81899	*O.rufipogon*	India	-	Sultanpur	Akhannagar	Mirapur	26°8'N	82°40'E	-
52	81901	*O.rufipogon x spontanea*	India	-	Ghazipur	Mirjabad	Mania	25°30'N	83°55'E	-
53	81910	*O.spontanea*	India	-	Gonda	Padri Karpal	Mudarwa Maphi	27°'N	81°58'E	-
54	82044	*O.granulata*	India	Kadaka	Koraput	Junagarh	Kavari Gondo	19°30'N	82°35'E	-

Figure 6.8 continued: List of populations and information of origin.

Sample No	AccNo IRRI or USDA	Species	Donor Country	Variety name	District	Town	Village	Latitude	Longi tude	Elevati on
55	100886	*O.punctata*	Japan	-	Cuttack	Central rice res. Inst.	-	-	-	-
56	100915	*O.nivara x sativa*	Japan	-	Calcutta	Darshin Barsat	-	-	-	-
57	101966	*O.nivara x rufipogon*	Japan	-	-	70 KM S of Jeypore	-	18°15'N	82°2'E	-
58	101969	*O.rufipogon x sativa*	Japan	-	-	68 KM N of Jeypore	-	19°28'N	82°35'E	-
59	101989	*O.rufipogon x sativa*	Japan	-	Dharwar	Alnawal	-	15°30'N	74°40'E	-
60	101990	*O.rufipogon x sativa*	Japan	-	Dharwar	Gonagu, Shiggaon	-	15°0'N	75°10'E	-
61	102168	*O.nivara x rufipogon*	Japan	-	Gorakhpur		-	26°0'N	83°30'E	-
62	104702	*O.nivara*	France	-	-	31 KM after Belgaum	Belgaum to Goa	-	-	-
63	104705	*O.nivara*	France	-	405 KM before Panvel	121 KM after Goa	Goa to Bombay	16°20'N	73°35'E	-
64	104707	*O.officinalis*	France	-	Dangs	Waghai to Pimpri	-	20°35'N	73°35'E	-
65	104709	*O.rufipogon*	France	-	9 KM before Belgaum	513 KM from Bengalore	Poona to Belgaum rd	16°0'N	74°30'E	-
66	105319	*O.nivara*	India	-	Trichur	20 KMS NW of Trichur	2 KMs from Poorima	10°10'N	76°10'E	-
67	105320	*O.nivara*	India	-	Palghat	34 KMS S of Palghat	Nammara	10°10'N	76°20'E	-
68	105333	*O.nivara*	India	-	Calicut	15 KMS E of Calicut	Mukkum	11°10'N	76°10'E	-

Figure 6.8 continued: List of populations and information of origin.

Sample No	AccNo IRRI or USDA	Species	Donor Country	Variety name	District	Town	Village	Latitude	Longi tude	Elevati on
69	105336	*O.nivara x sativa*	India	-	Calicut	10 KMS N of Calicut	Chamencherry	11°5'N	75°55'E	-
70	105708	*O.nivara*	India	Madras 2	-	21 KMS SE of Madras	Kanesh	12°50'N	80°0'E	-
71	106048	*O.nivara*	India	-	-	Baripada	5 KM N of Baripada	21°55'N	86°30'E	-
72	106065	*O.nivara*	India	Pasaha	-	Ranchi	Kanke	23°7'N	85°2'E	-
73	106444	*O.granulata*	India	-	Pathanmathitta	Muillumala	Cheruettakavu	9°'N	76°30'E	-
74	106445	*O.granulata*	India	-	Nulumbar	Karulai Range	Valromkulur	11°'N	76°30'E	-
75	36807	*O.sativa*	Bhutan	Thimphu Local	-	-	-	27o 30N	90o 30 E	-
76	3638	*O.sativa*	United States	Kamod	Hyderabad	-	-	17o 23N	780 28 E	480 m
77	3643	*O.sativa*	United States	Ramgarh	Chota Nagpur	-	-	23o 00N	85o 00 E	548 m
78	1608	*O.sativa*	India	White Halga	Karnataka	-	-			-
79	45975	*O.sativa*	India	Kalamati	West Bengal	-	-	23 00N	87o 59 E	-
80	CI 8092	*O.sativa*	India	Vulgaris	Tamil Nadu	-	-	11o 00N	78o 00 E	-
81	10601	*O.sativa*	United States	Dhoke 6	Maharastra, India	-	-	18o 32N	73o 52E	592 m
82	33188	*O.sativa*	Myanmar	Kaukkyi Ani	Myanmar	-	-	22o 00 N	98o 00 E	-

Figure 6.8 continued: List of populations and information of origin.

Sample No	AccNo IRRI or USDA	Species	Donor Country	Variety name	District	Town	Village	Latitude	Longi tude	Elevati on
83	27630	*O.sativa*	Nepal	Darwali	Bagmati	Palung Valley, Makawanpur	-	27o 38 N	85o 04E	2259 m
84	GT	*O.sativa*	Thailand	-	Chouburi Province	-	-	-	-	-
85	431084	*O.sativa*	Myanmar	Dsi Sel Dangar Shah	Myanmar	-	-	22o 00 N	98o 00 E	-
86	12894	*O.sativa*	India	Gompa 2	Sikkim, India	-	-	27o 45 N	88o 30 E	-
87	EH	*O.sativa*	India	-	Bhubaneshwar market	-	-	-	-	-

Figure 6.8 continued: List of populations and information of origin.

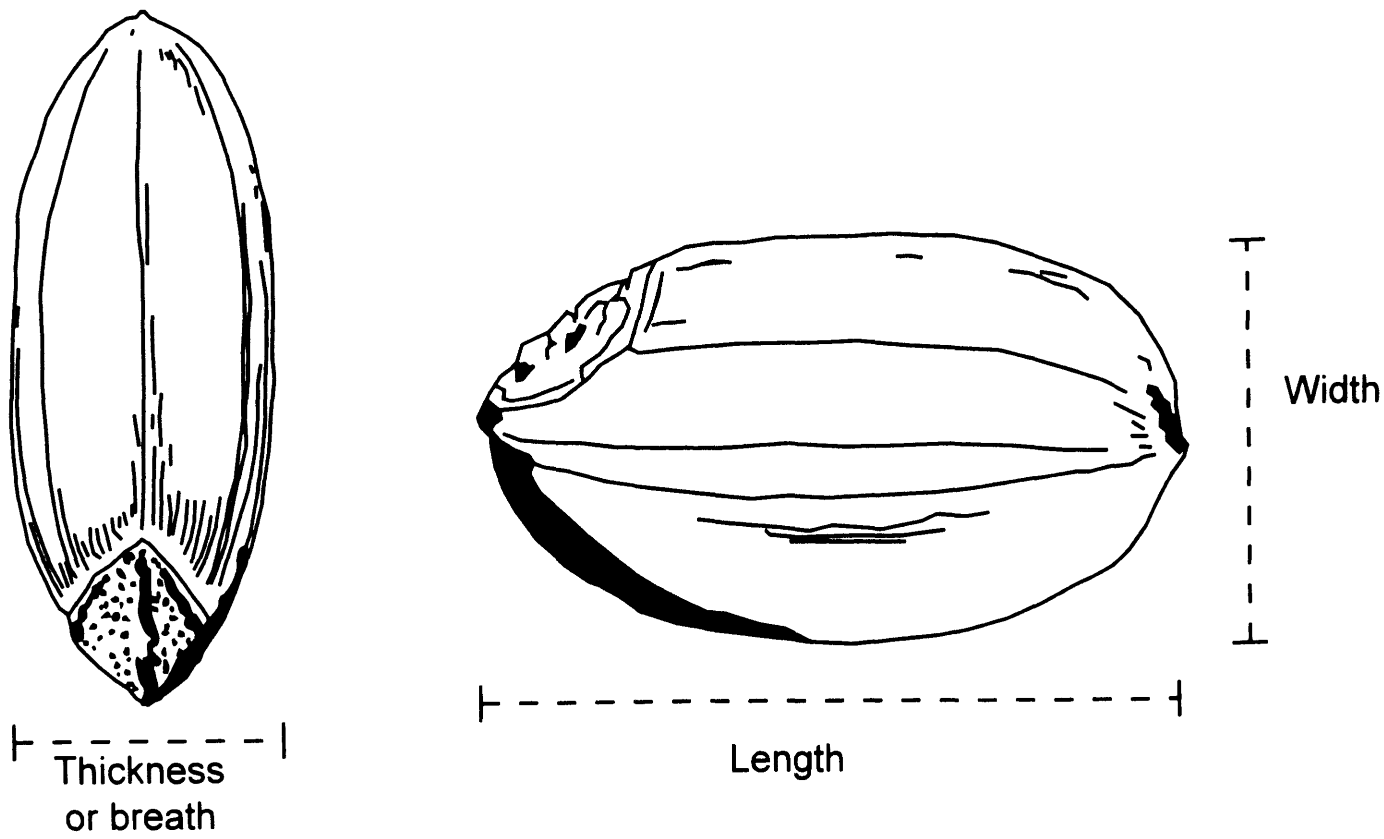


Figure 6.9: Diagram of how grain measurements taken in this project.

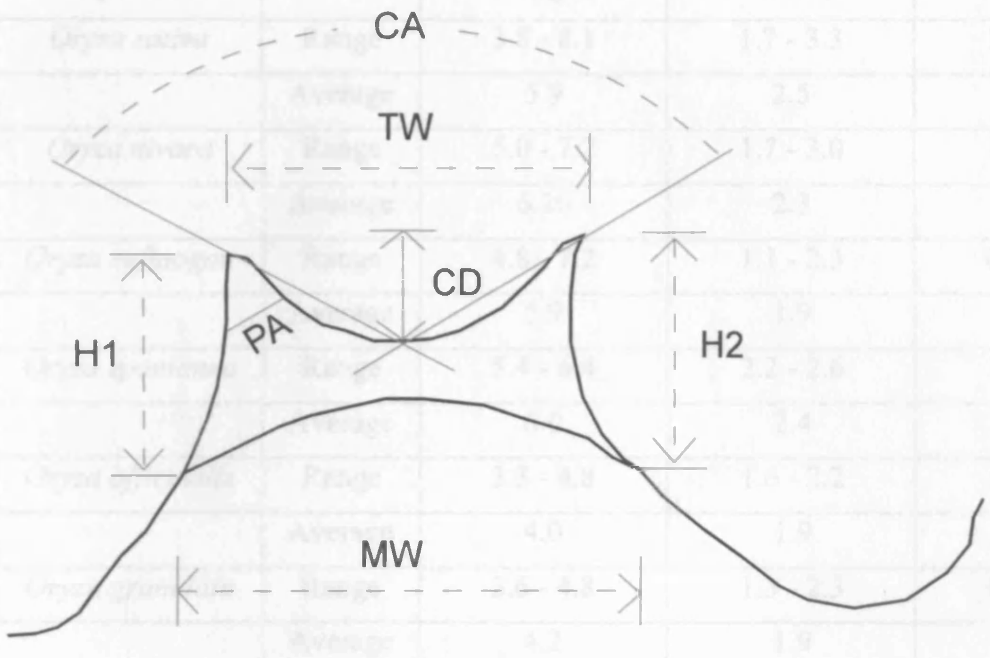


Figure 6.10: Diagram of double-peaked husk cell with measurements that were taken in this project (after Zhao et al. 1998).

Species		Length	Width	Thickness
Oryza sativa	Range	3.8 - 8.1	1.7 - 3.3	1.2 - 2.3
	Average	5.9	2.5	1.9
Oryza nivara	Range	5.0 - 7.7	1.7 - 3.0	1.0 - 2.1
	Average	6.20	2.3	1.6
Oryza rufipogon	Range	4.8 - 7.2	1.1 - 2.3	0.9 - 1.8
	Average	5.9	1.9	1.4
Oryza spontanea	Range	5.4 - 6.4	2.2 - 2.6	1.5 - 2.0
	Average	6.0	2.4	1.7
Oryza officinalis	Range	3.3 - 4.8	1.6 - 2.2	1.0 - 1.5
	Average	4.0	1.9	1.2
Oryza granulata	Range	3.6 - 4.8	1.3 - 2.3	1.0 - 1.6
	Average	4.2	1.9	1.4
Oryza punctata	Range	3.9 - 4.6	1.7 - 2.0	1.1 - 1.3
	Average	4.2	1.8	1.2

Figure 6.11: Table showing the ranges and averages for rice grain measurements.

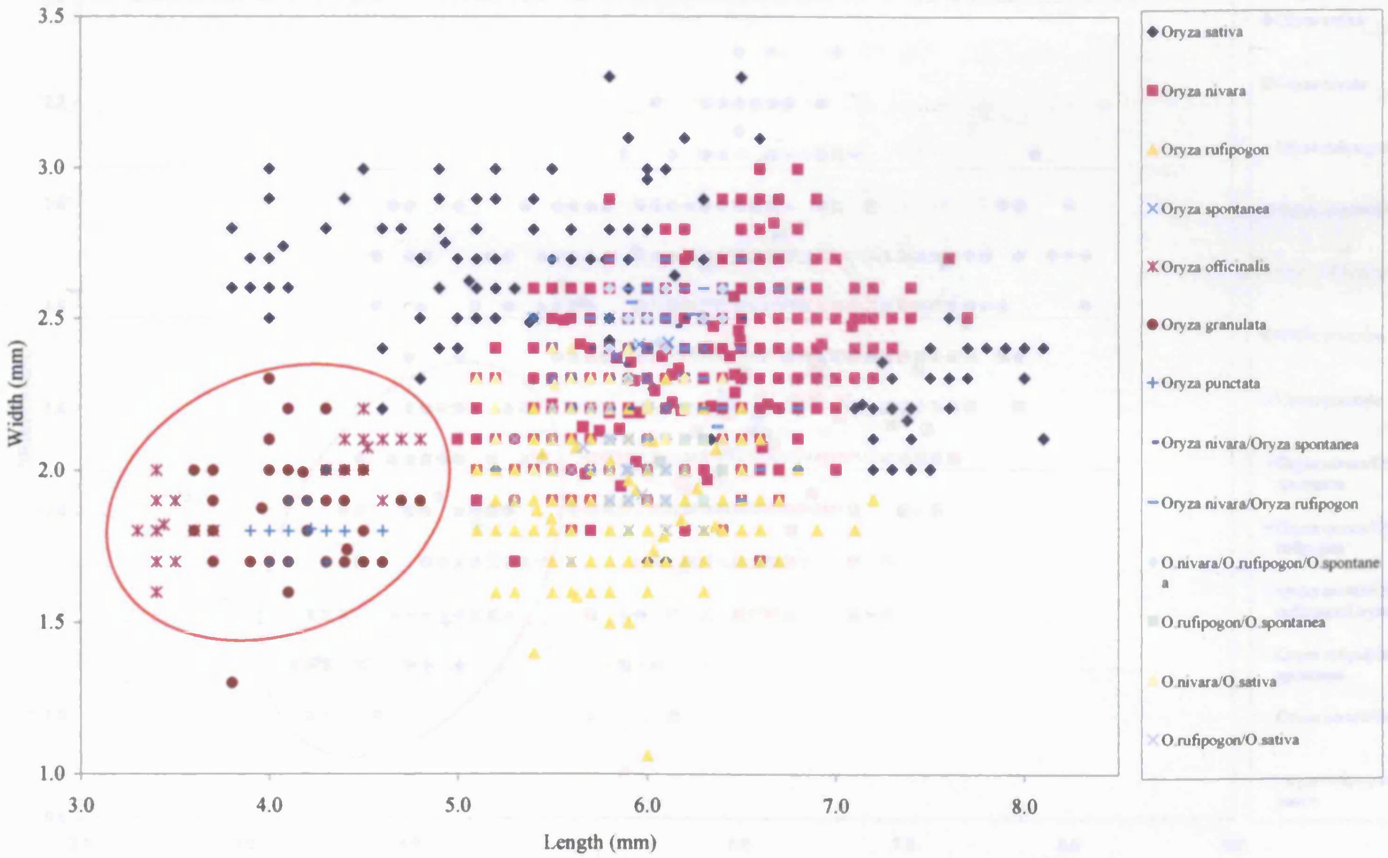


Figure 6.12: Graph showing the length and width measurements for individual grains in each population for each species. Red circle shows the separation of the small wild rice species from the Sativa complex grains.

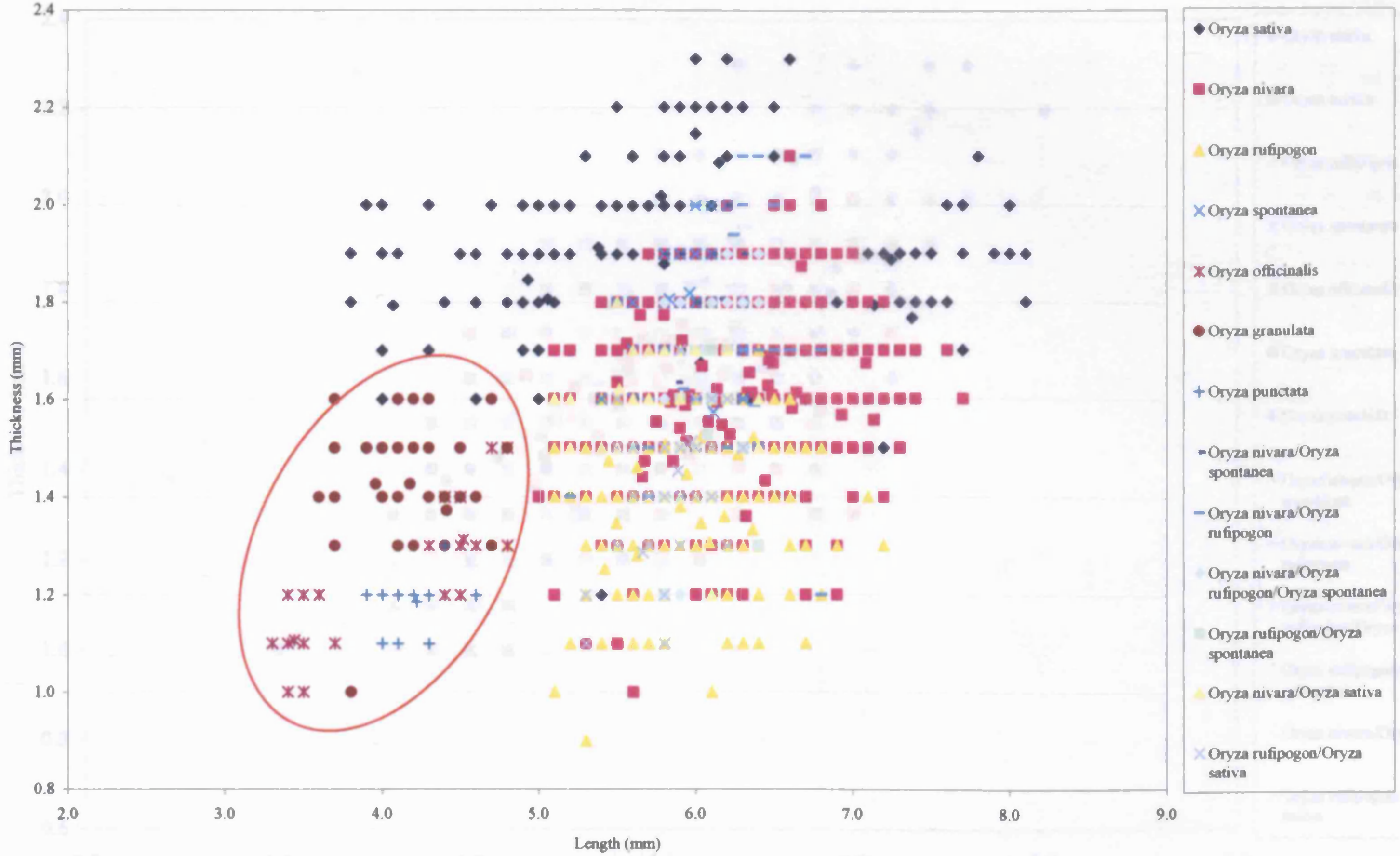


Figure 6.13: Graph showing the length and thickness measurements for individual grains in each population for each species. Red circle shows the separation of the small wild rice species and the Sativa complex grains.

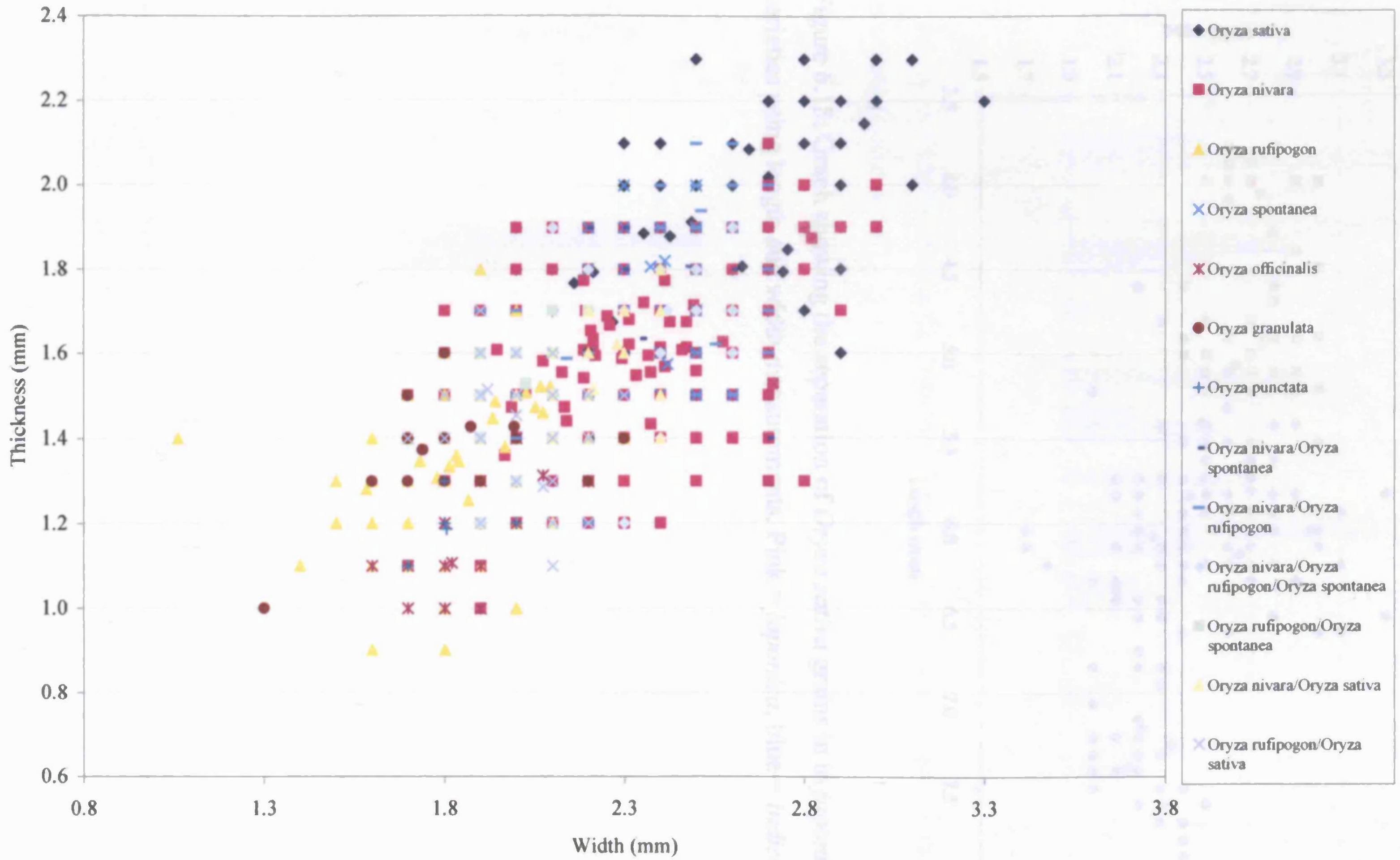


Figure 6.14: Graph showing the width and thickness measurements for individual grains in each population for each species.

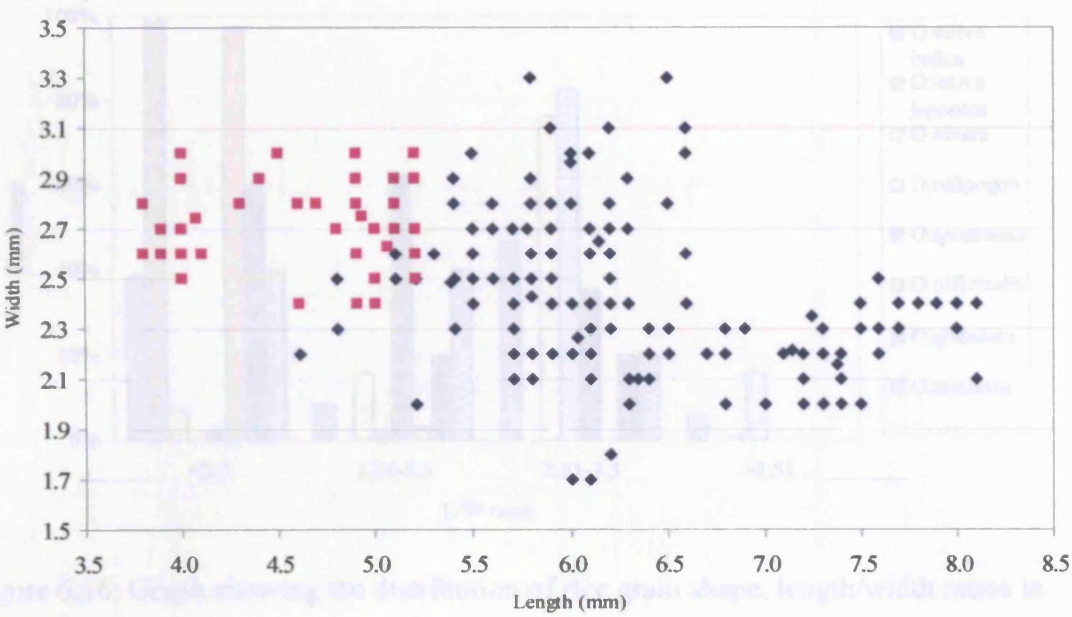


Figure 6.15: Graph showing the separation of *Oryza sativa* grains in to *japonica* and *indica* varieties using length and width measurements. Pink = *japonica*, blue = *indica*.

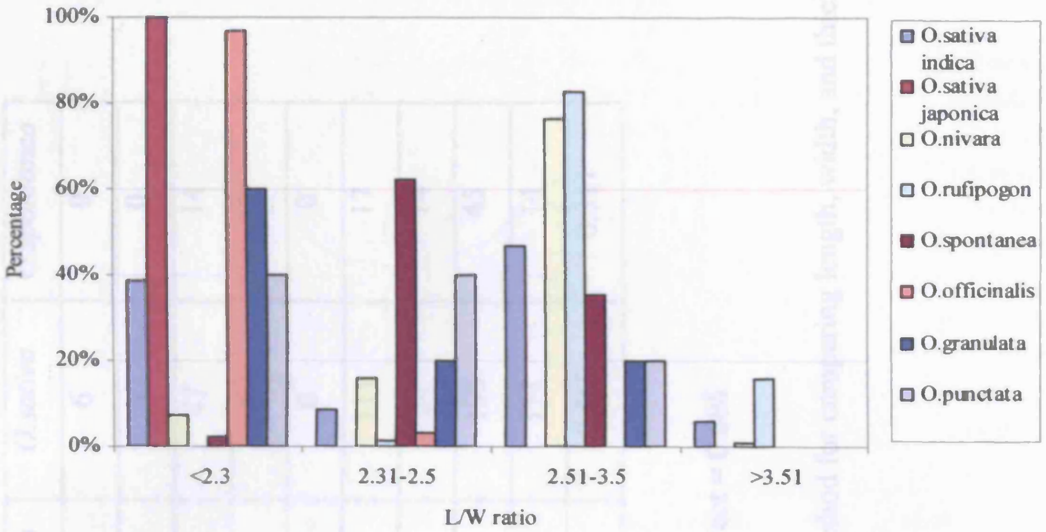


Figure 6.16: Graph showing the distribution of rice grain shape, length/width ratios in percentage occurrence.

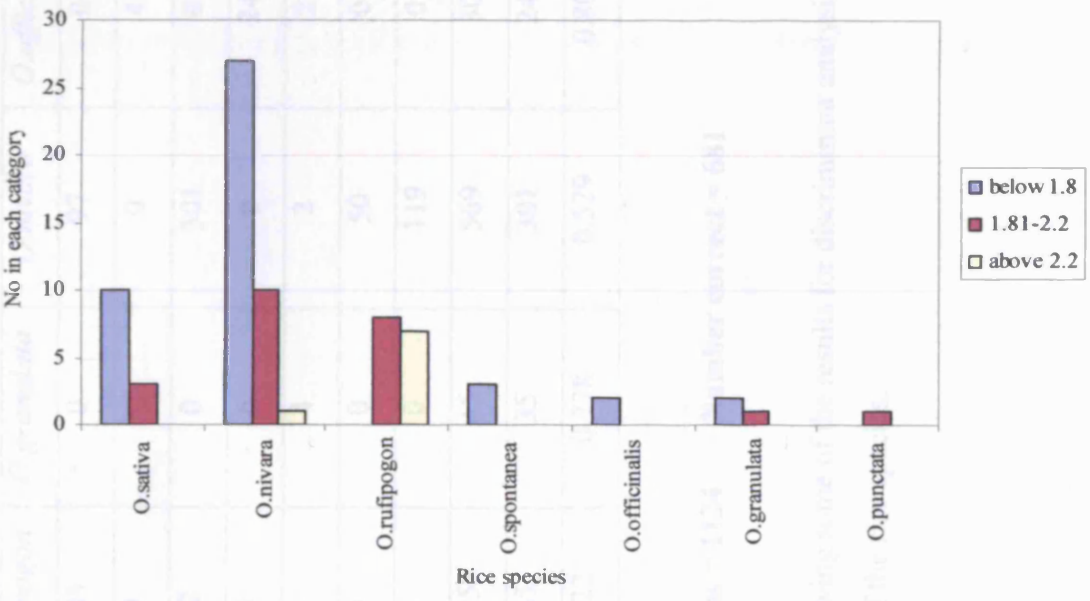


Figure 6.17: Graph showing how the new measurements from this thesis fit in to Vishnu-Mittre's (1972.1974) categories for identifying rice species.

Group	*O.rufipogon*	*O.granulata*	*O.nivara*	*O.officinalis*	*O.punctata*	*O.sativa*	*O.spontanea*
O.rufipogon	185	0	97	0	0	6	0
O.granulata	0	35	0	4	1	4	0
O.nivara	32	0	301	0	0	47	14
O.officinalis	0	6	0	24	3	3	0
O.punctata	5	4	2	2	11	0	0
O.sativa	0	0	50	0	0	111	17
O.spontanea	3	0	119	0	0	24	14
Total N	225	45	569	30	15	195	45
N Correct	185	35	301	24	11	111	14
Proportion	0.822	0.778	0.529	0.800	0.733	0.569	0.311

Total number of grains = 1124 **Number correct = 681** **Proportion correct = 0.606**

Figure 6.18: Table showing some of the results for discriminant analysis using the linear method for comparing length, width, and thickness measurements for all of the rice species.

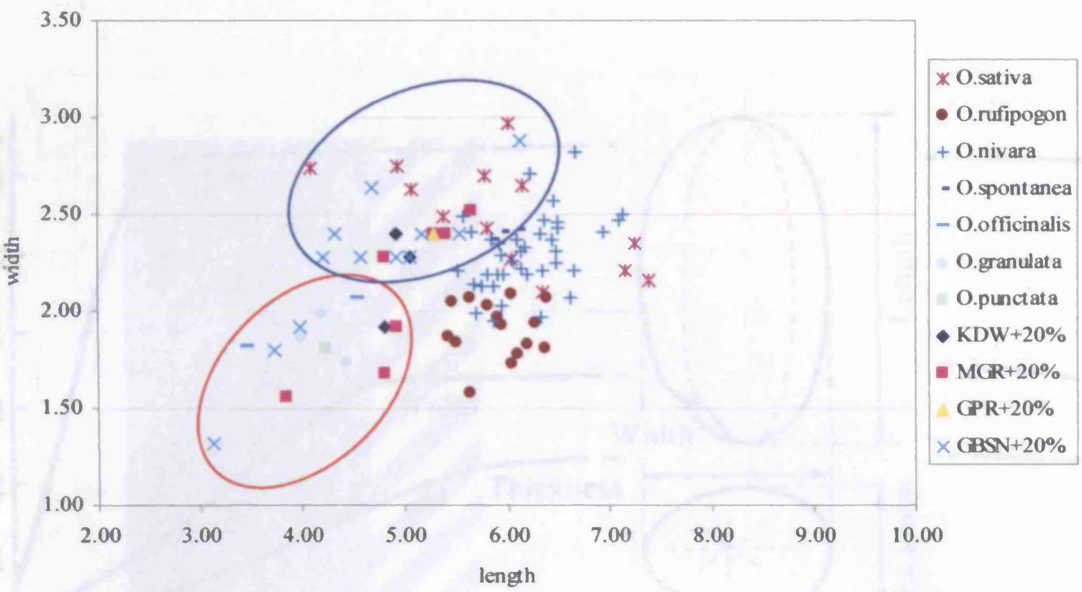


Figure 6.19: Graph showing a comparison of the length and width measurements of modern and archaeological rice grains. The archaeological grains are adjusted for 20% shrinkage. Red circle shows the archaeological grains that may be classified as small wild rice species and the blue circle shows those that could be from the Sativa complex of rice species.

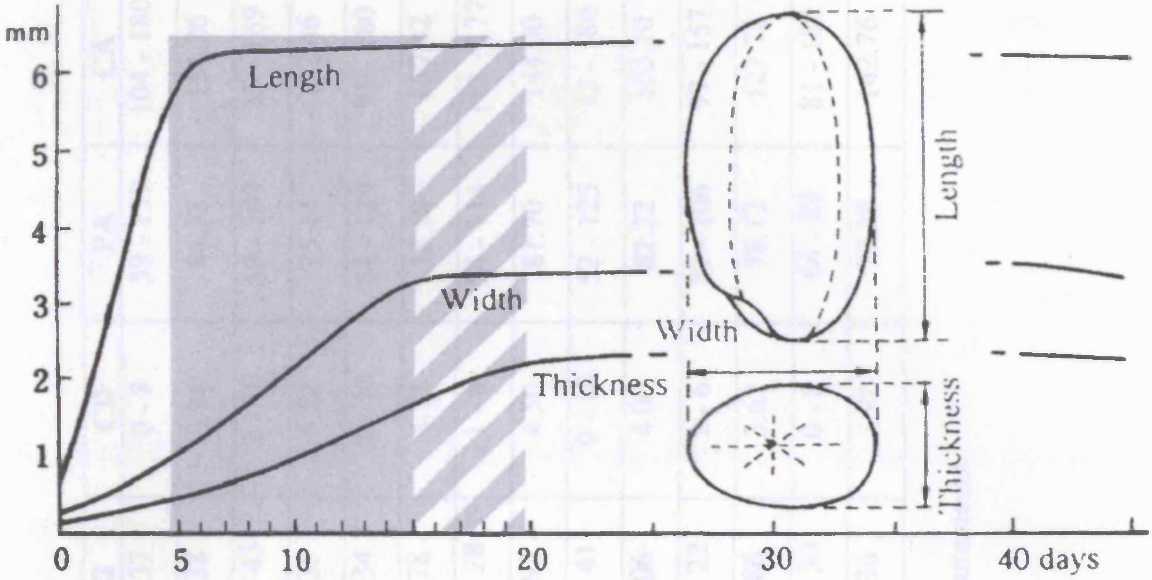


Figure 6.20: Graph showing the maturing rates for *Oryza sativa* subsp. *japonica*

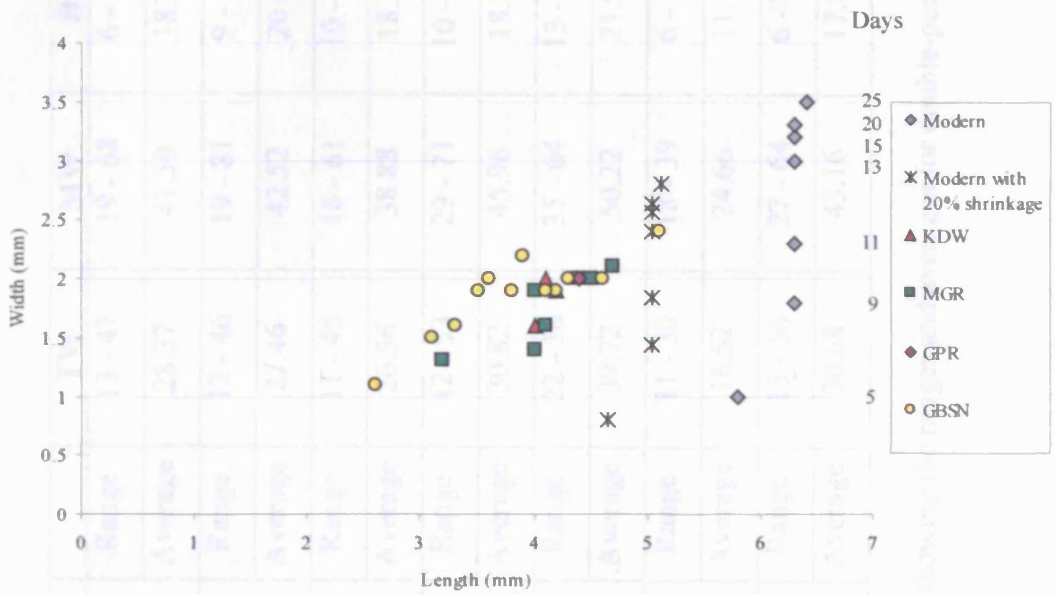


Figure 6.21: Graph comparing the immature measurements of modern and archaeological rice grains. Red circle shows the possible small wild rice species and blue circle shows the possible immature Sativa complex grains, although some of the slightly larger ones may be mature and therefore possibly domestic rice.

Species		TW	MW	H1	H2	CD	PA	CA
Oryza sativa	Range	13 - 47	19 - 68	6 - 32	6 - 37	0 - 8	59 - 139	104 - 180
	Average	28.37	41.50	18.96	19.38	3.94	84.38	151.26
Oryza nivara	Range	12 - 46	19 - 81	9 - 39	11 - 43	2 - 10	50 - 109	85 - 169
	Average	27.46	42.52	20.02	21.35	5.32	75.44	132.46
Oryza rufipogon	Range	11 - 45	16 - 61	10 - 31	6 - 34	0 - 10	54 - 129	91 - 180
	Average	26.56	38.88	18.36	18.78	4.33	78.58	139.42
Oryza spontanea	Range	12 - 53	29 - 71	10 - 29	12 - 28	1 - 8	54 - 114	111 - 177
	Average	30.82	45.96	18.28	18.92	4.50	81.70	144.00
Oryza officinalis	Range	22 - 56	35 - 64	13 - 32	12 - 41	0 - 10	52 - 125	12 - 180
	Average	39.72	50.22	21.96	22.06	4.00	82.22	155.10
Oryza granulata	Range	11 - 30	18 - 39	6 - 21	16 - 22	2 - 6	59 - 106	97 - 157
	Average	16.52	24.66	11.44	11.86	3.62	78.12	127.78
Oryza punctata	Range	13 - 56	27 - 64	6 - 28	11 - 30	0 - 8	64 - 89	81 - 180
	Average	30.68	43.16	17.88	18.36	3.92	78.28	142.76

Figure 6.22: Table showing the ranges and averages for double-peaked rice measurements.

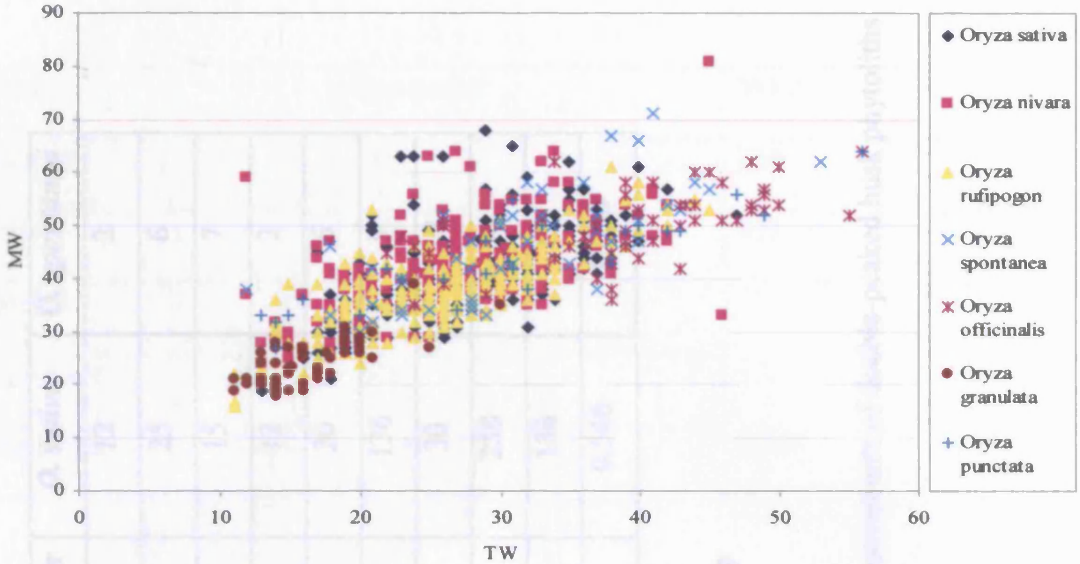


Figure 6.23: Graph showing the TW and MW values for individual phytoliths from each rice species.

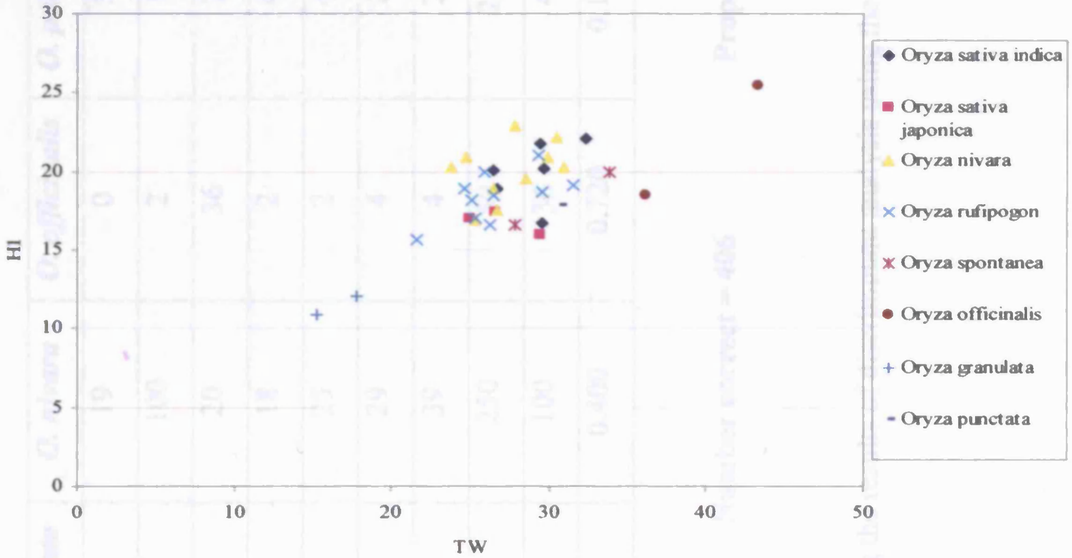


Figure 6.24: Graph showing the TW and H1 averages for each population for each rice species.

Group	O.granulata	O. nivara	O. officinalis	O. punctata	O. rufipogon	O. sativa	O. spontanea
O. granulata	48	19	0	5	20	12	2
O. nivara	0	100	2	1	44	25	6
O. officinalis	0	20	36	7	15	15	7
O. punctata	0	18	2	4	23	12	2
O. rufipogon	0	25	2	4	64	20	6
O. sativa	2	29	4	2	60	136	9
O. spontanea	0	39	4	2	24	30	18
Total N	50	250	50	25	250	250	50
N Correct	48	100	36	4	64	136	18
Proportion	0.960	0.400	0.720	0.160	0.256	0.546	0.360

Number = 925 **Number correct = 406** **Proportion correct = 0.439**

Figure 6.25: Table showing the results of discriminant analysis using the linear method for measurements of double-peaked husk phytoliths for all rice species.

Group	Domestic	Wild
Domestic	181	204
Wild	69	471
Total N	250	675
N Correct	181	471
Proportion	0.724	0.698

Total number = 925 **Number correct = 652** **Proportion correct = 0.705**

Figure 6.26: Table showing the results of discriminant analysis using the linear method for all measurements (TW, MW, H1, H2, CD, PA, CA) of double-peaked husk phytoliths using wild versus domestic categories.

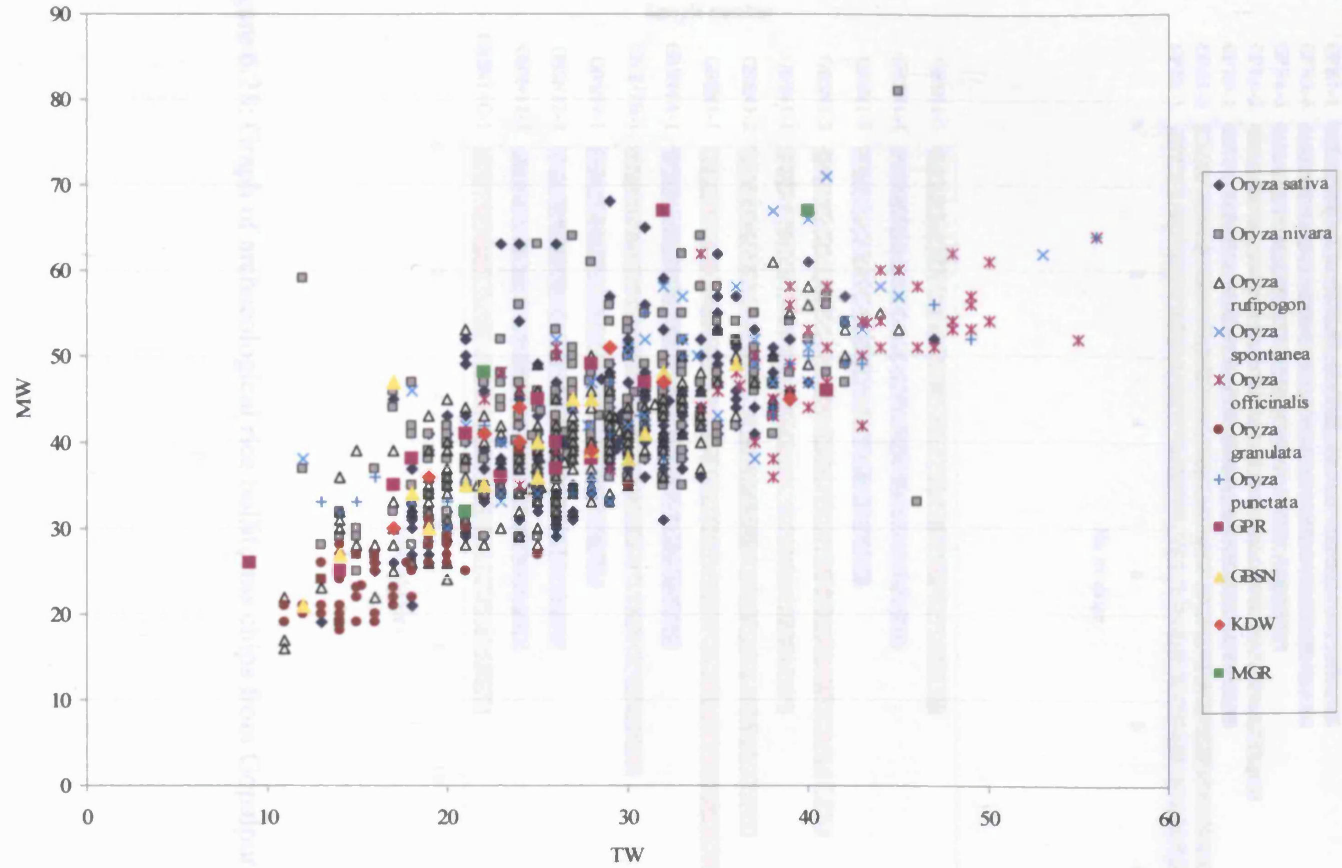
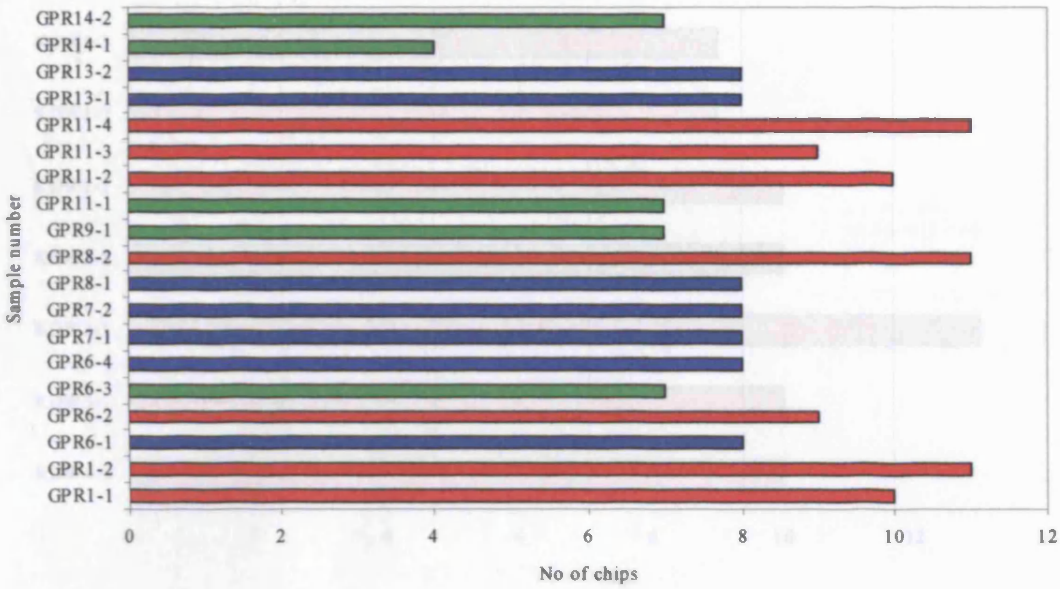


Figure 6.27: Graph showing archaeological and modern double-peaked husk phytolith measurements.



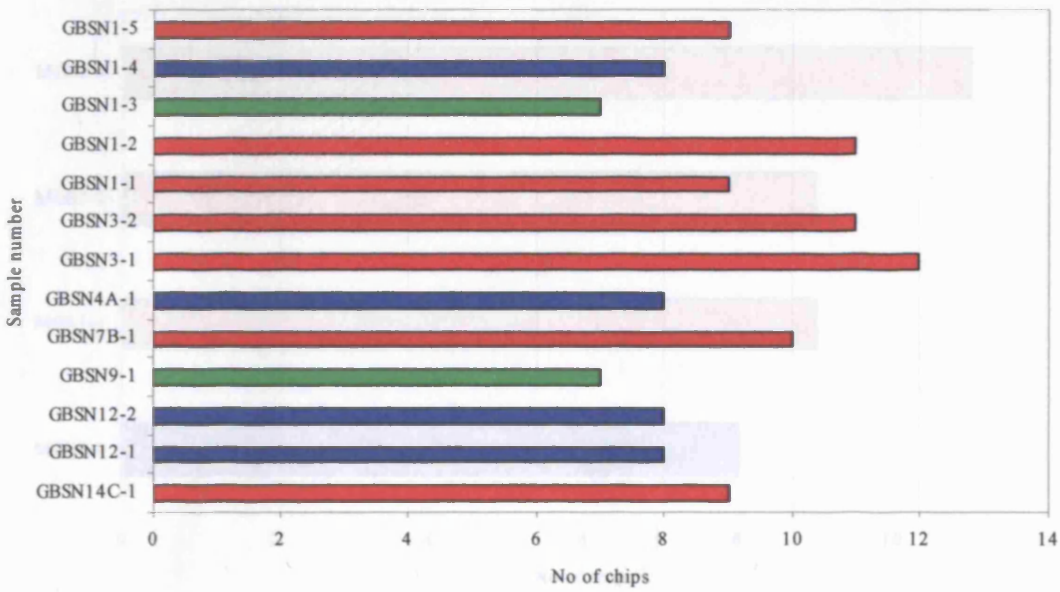
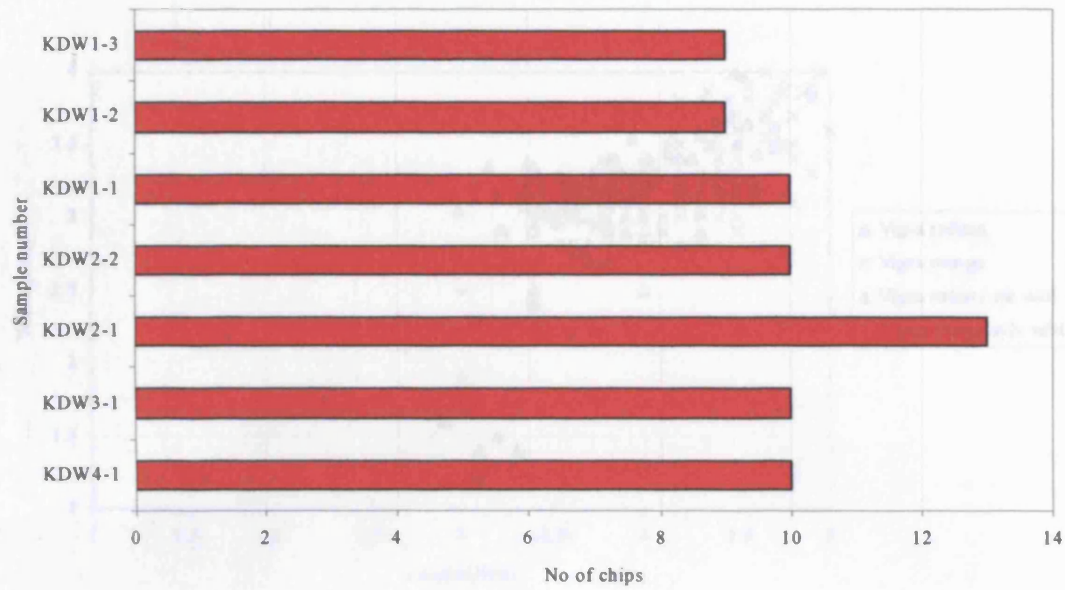


Figure 6.28: Graph of archaeological rice bulliforms chips from Gopalpur and Golbai Sasan



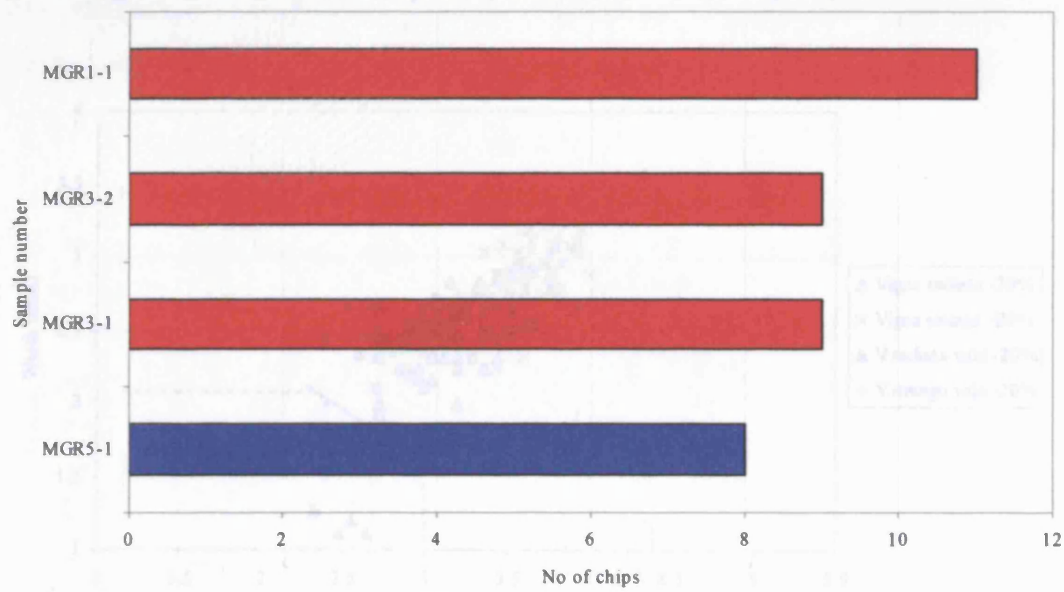


Figure 6.29: Graph of archaeological rice bulliform chips from Mahagara and Koldihwa.

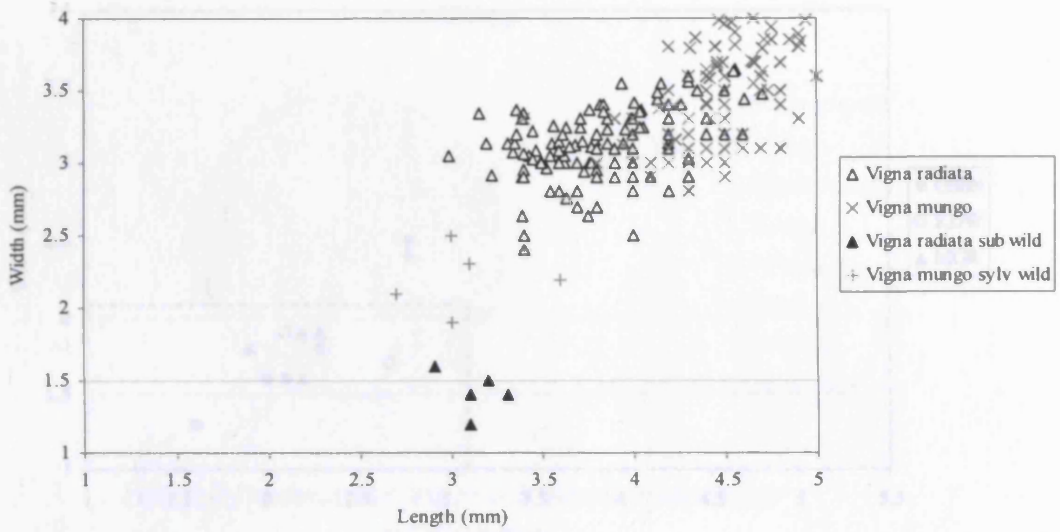


Figure 7.1: Graph showing modern length and width measurements of *Vigna radiata* and *Vigna mungo* (wild and domestic species) (after Fuller & Harvey in press).

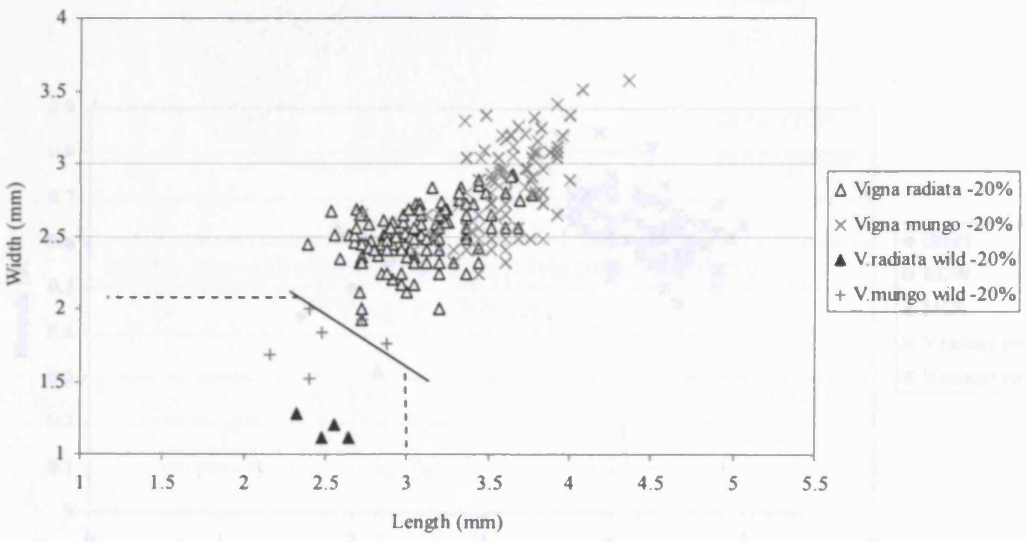


Figure 7.2: Graph showing modern length and width measurements of *Vigna radiata* and *Vigna mungo* (wild and domestic species) with 20% shrinkage adjustment (after Fuller & Harvey in press).

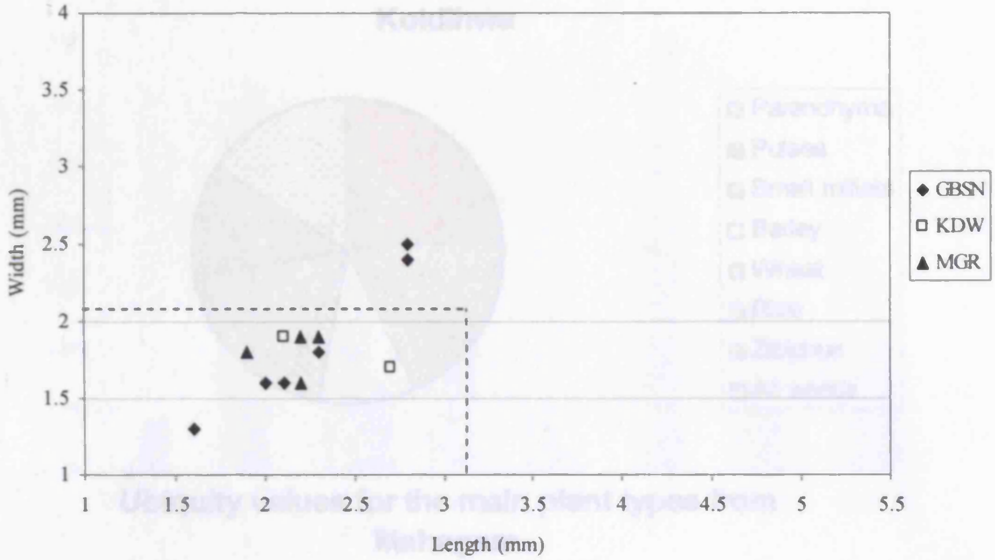


Figure 7.3: Graph showing archaeological length and width measurements for *Vigna* sp. seeds with dashed line separating possible wild from possible domestic types (after Fuller & Harvey in press).

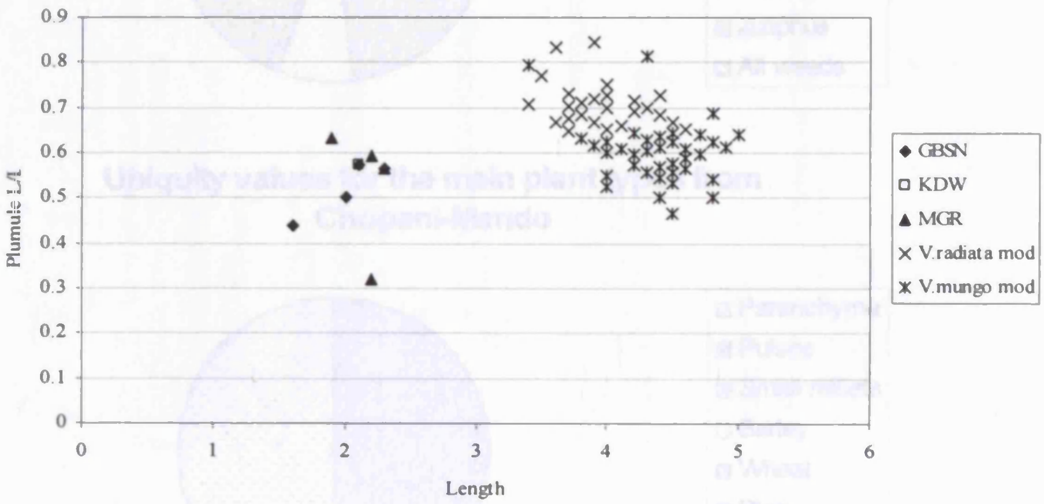
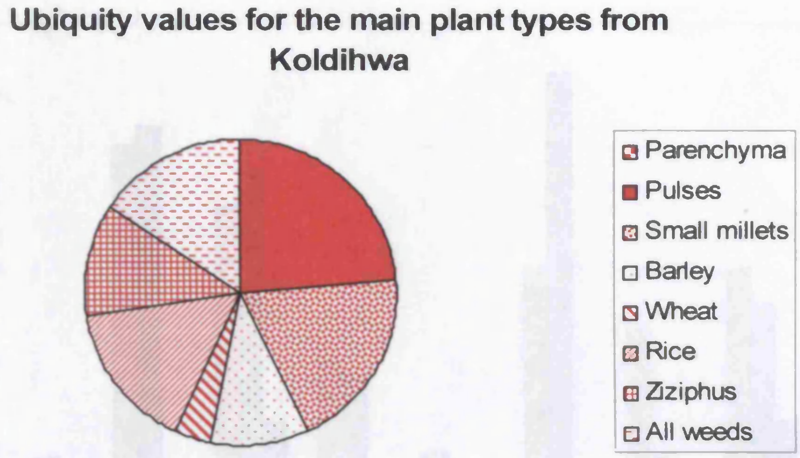
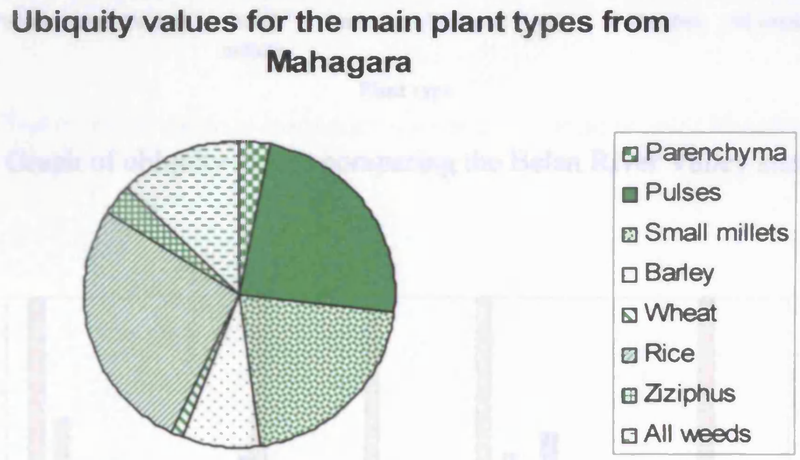


Figure 7.4: Graph showing length vs plumule length/length measurements for identifying *Vigna mungo* and *Vigna radiata* (after Fuller & Harvey in press).





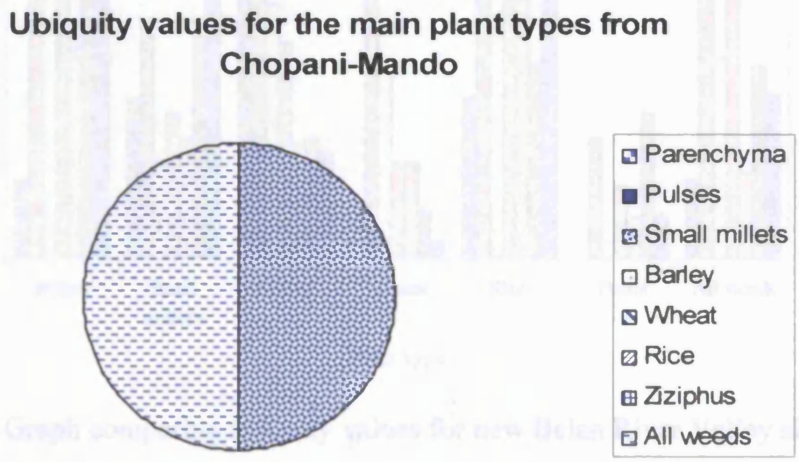


Figure 7.5: Ubiquity pie charts for sites in the Belan River Valley.

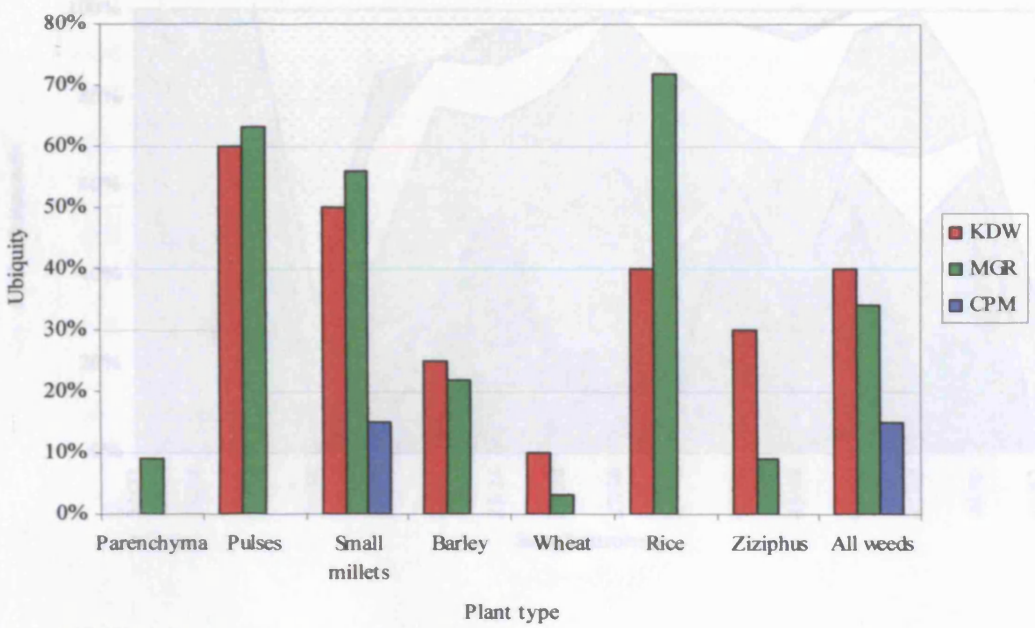


Figure 7.6: Graph of ubiquity values comparing the Belan River Valley sites.

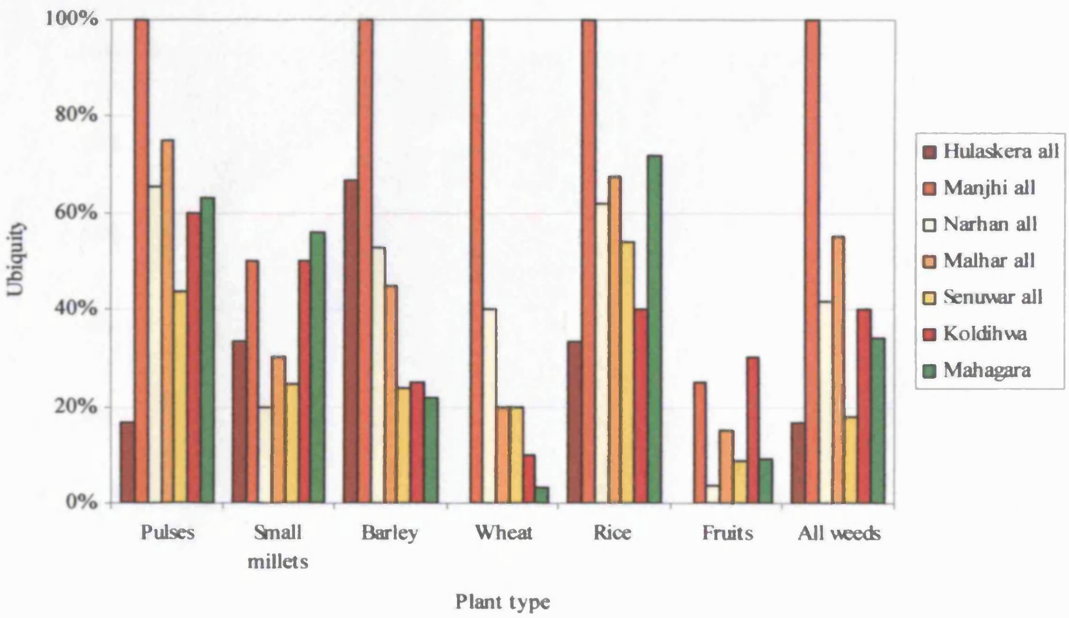


Figure 7.7: Graph comparing ubiquity values for new Belan River Valley sites and the published North Indian sites.

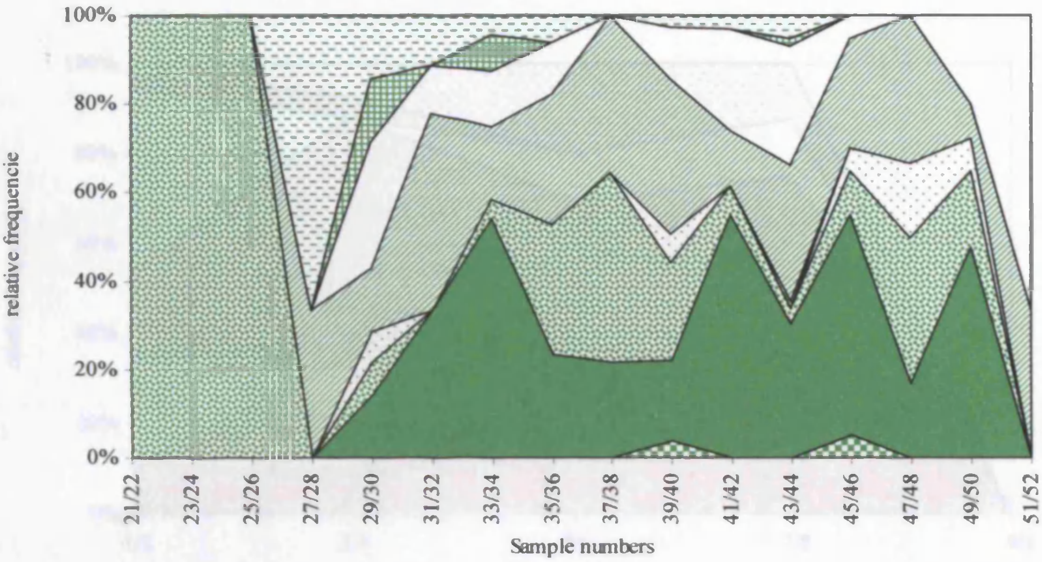


Figure 7.8: Bar chart of relative frequencies of macro-remains from Mahagara.

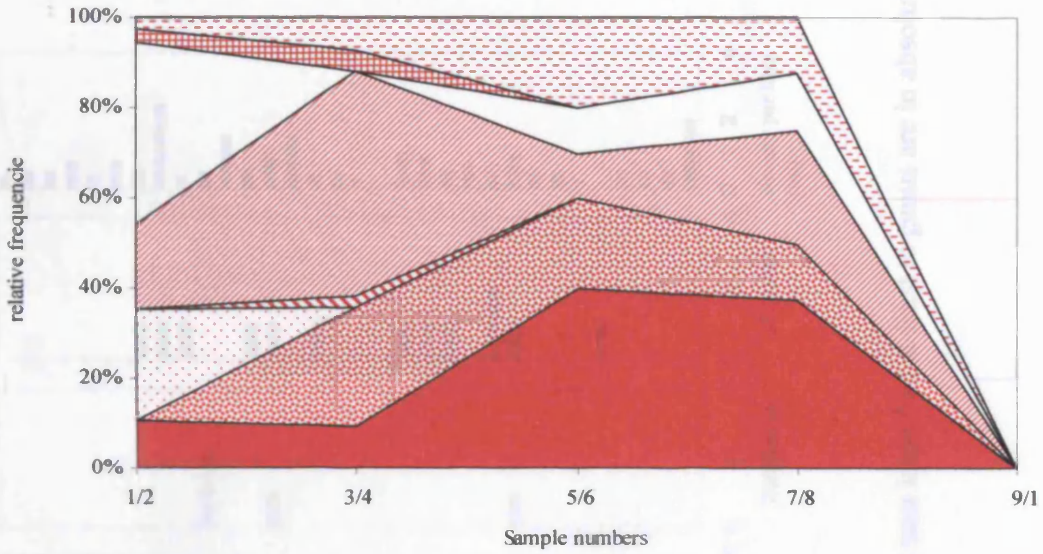


Figure 7.9: Bar chart of relative frequencies of macro-remains in Z1 section from Koldihwa.

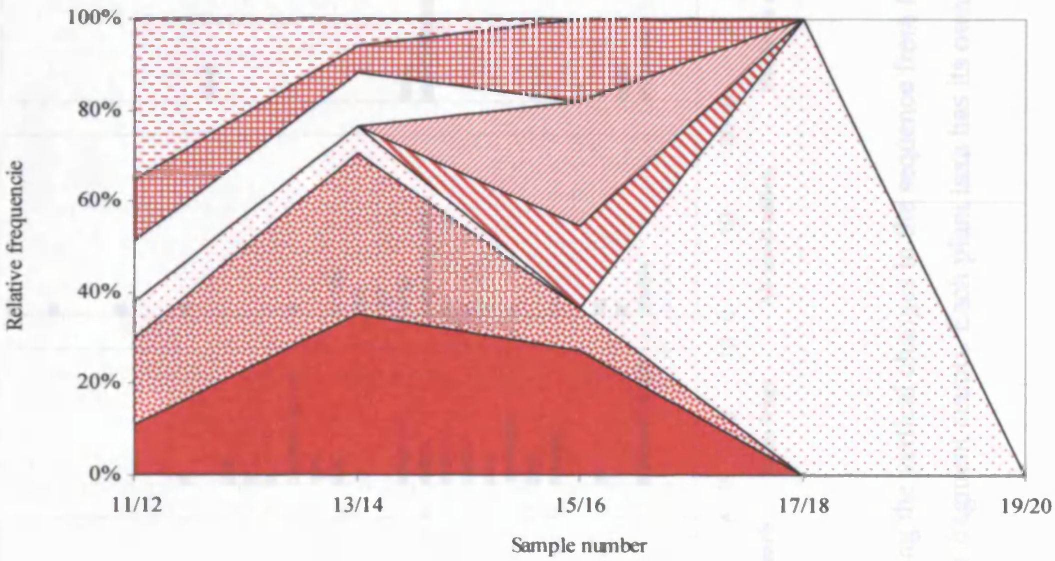


Figure 7.10: Bar chart of relative frequencies of macro-remains in Y1 sections from Koldihwa.

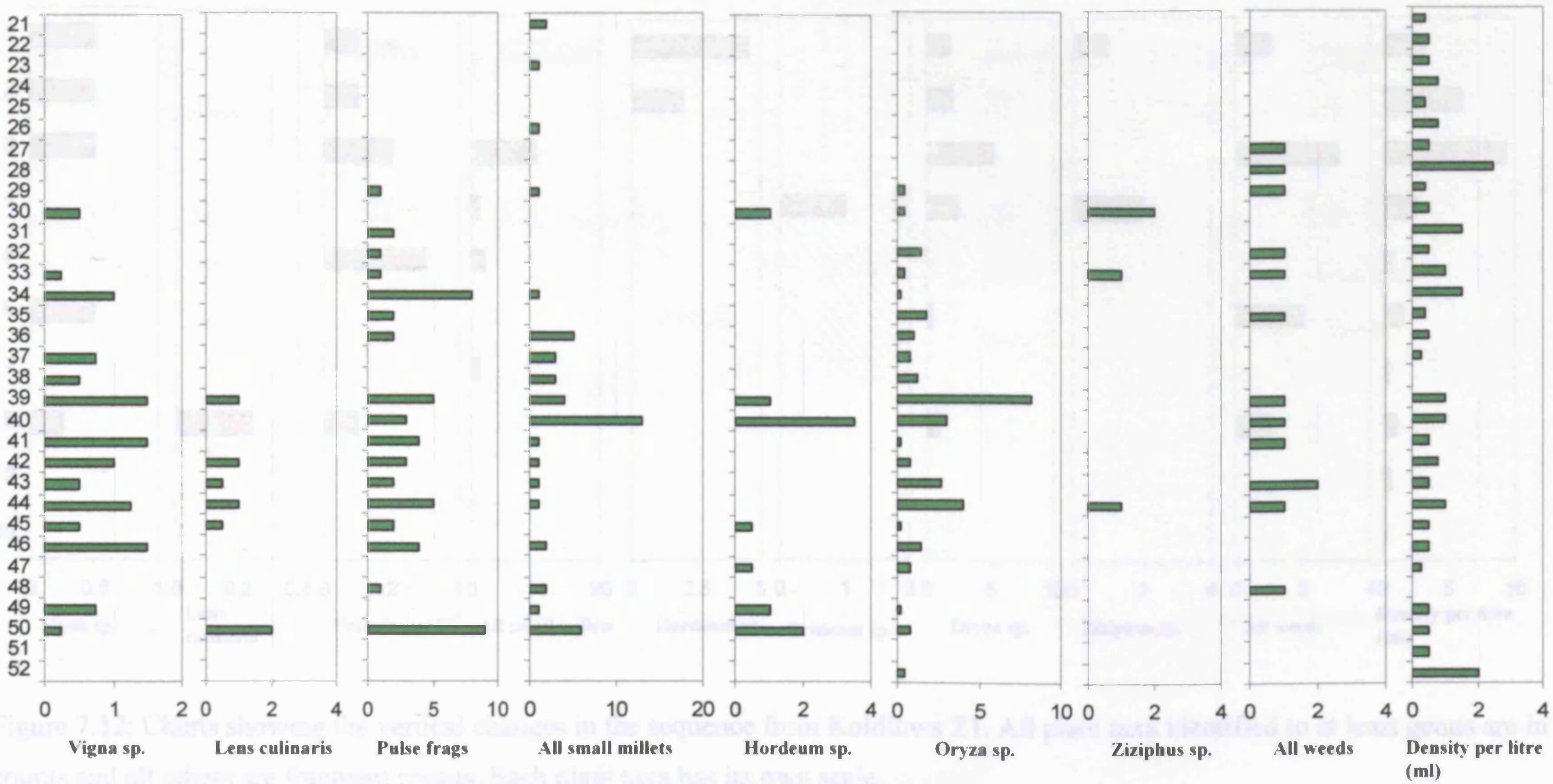


Figure 7.11: Charts showing the vertical changes in the sequence from Mahagara. All plant taxa identified at least to genus are in absolute numbers and all others are fragment counts. Each plant taxa has its own scale.

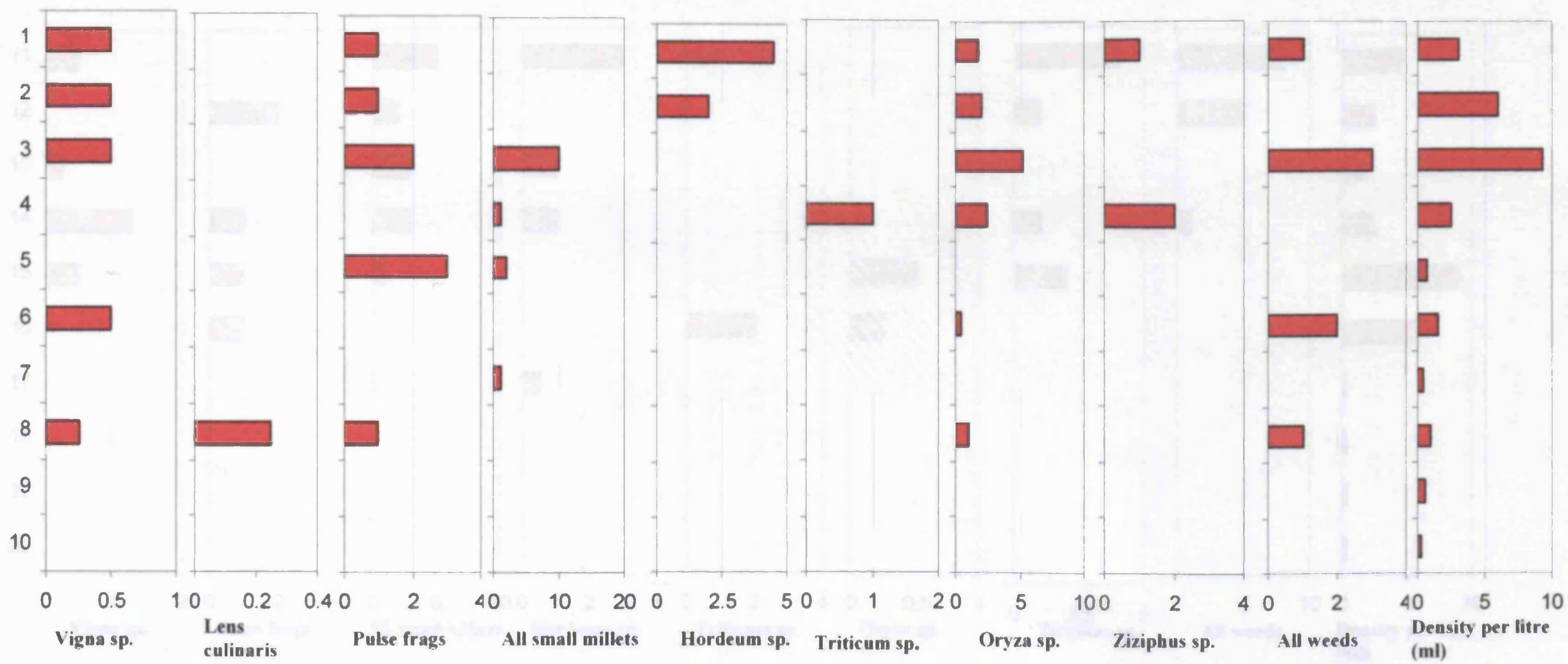


Figure 7.12: Charts showing the vertical changes in the sequence from Koldihwa Z1. All plant taxa identified to at least genus are in absolute counts and all others are fragment counts. Each plant taxa has its own scale.

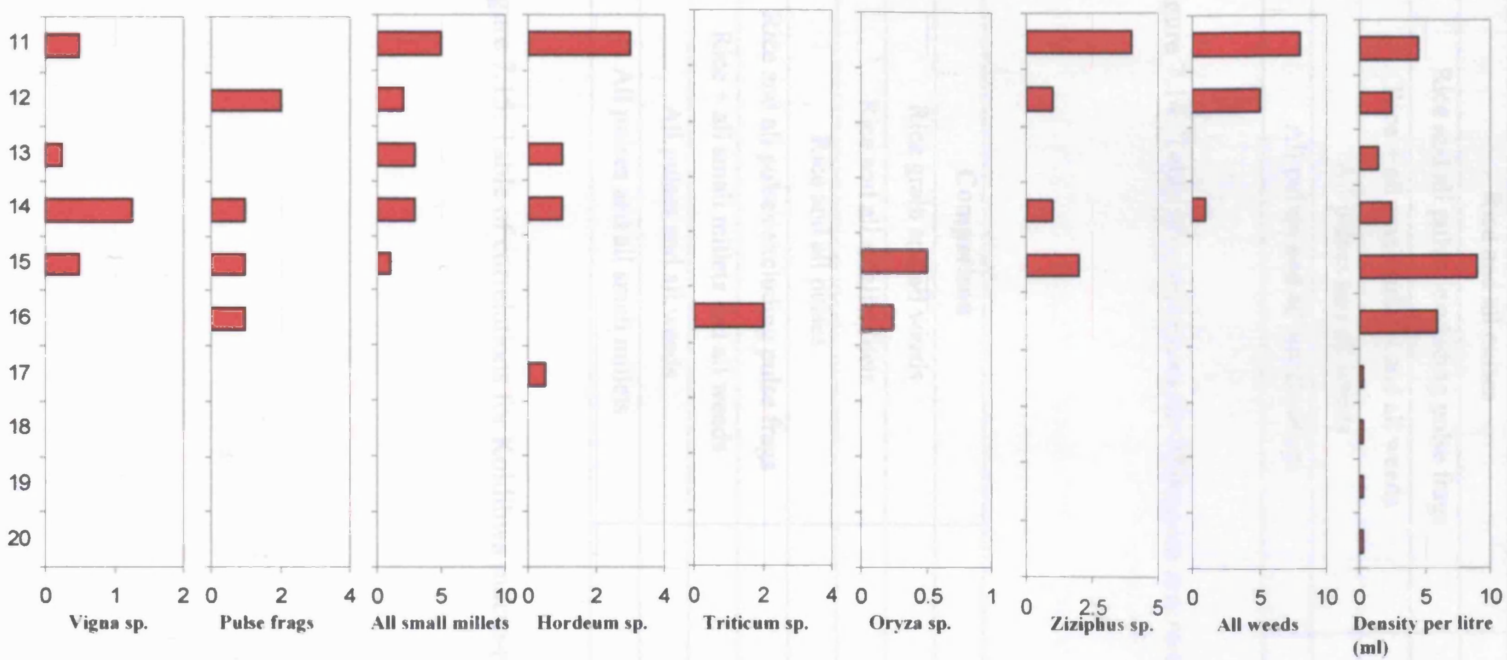


Figure 7.13: Charts showing the vertical changes in the sequence from Koldihwa Y1. All plant taxa identified to at least genus are in absolute counts and all others are fragment counts. Each plant taxa has its own scale.

Comparison	R^2 value
Rice grain and all weeds	0.1957
Rice and all small millets	0.1516
Rice and all pulses	0.2427
Rice and all pulses excluding pulse frags	0.3459
Rice + all small millets and all weeds	0.0726
All pulses and all weeds	0.0142
All pulses and all small millets	0.1184

Figure 7.14: Table of correlations for Mahagara macro-remains.

Comparison	R^2 value
Rice grain and all weeds	0.0094
Rice and all small millets	0.347
Rice and all pulses	0.1352
Rice and all pulses excluding pulse frags	0.0607
Rice + all small millets and all weeds	0.1883
All pulses and all weeds	0.0506
All pulses and all small millets	0.2116

Figure 7.15: Table of correlations for Koldihwa macro-remains.

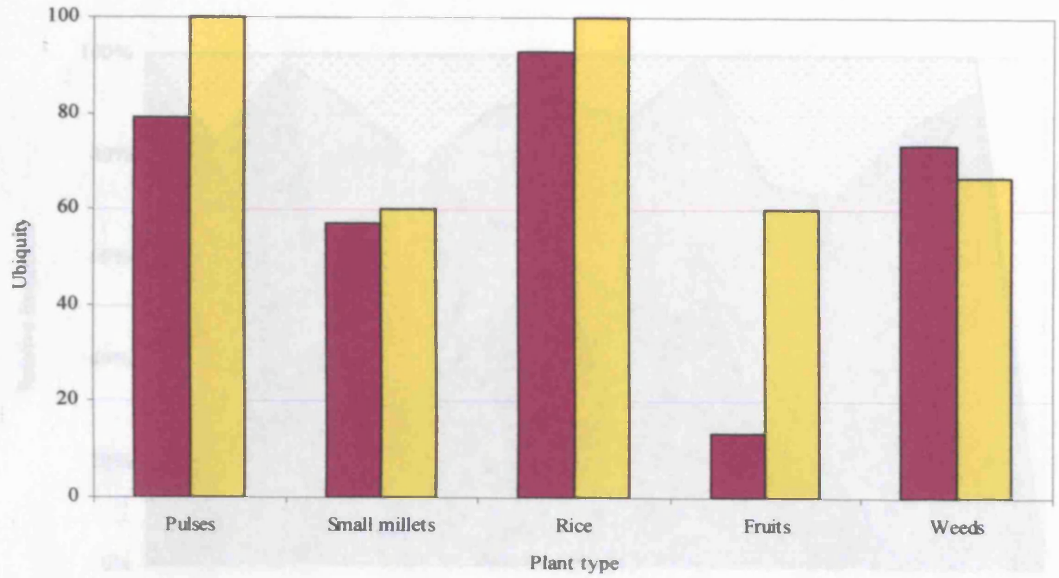


Figure 7.16: Graph of ubiquity values from Gopalpur (purple) and Golbai Sasan (yellow).

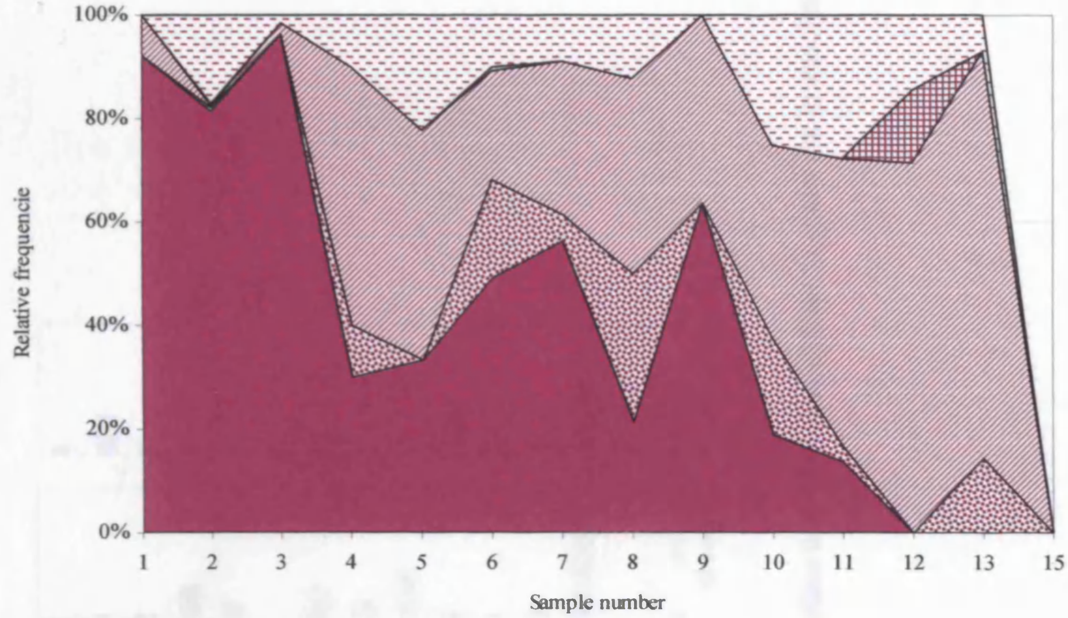


Figure 7.17: Bar chart of the relative frequencies of macro-remains from Gopalpur.

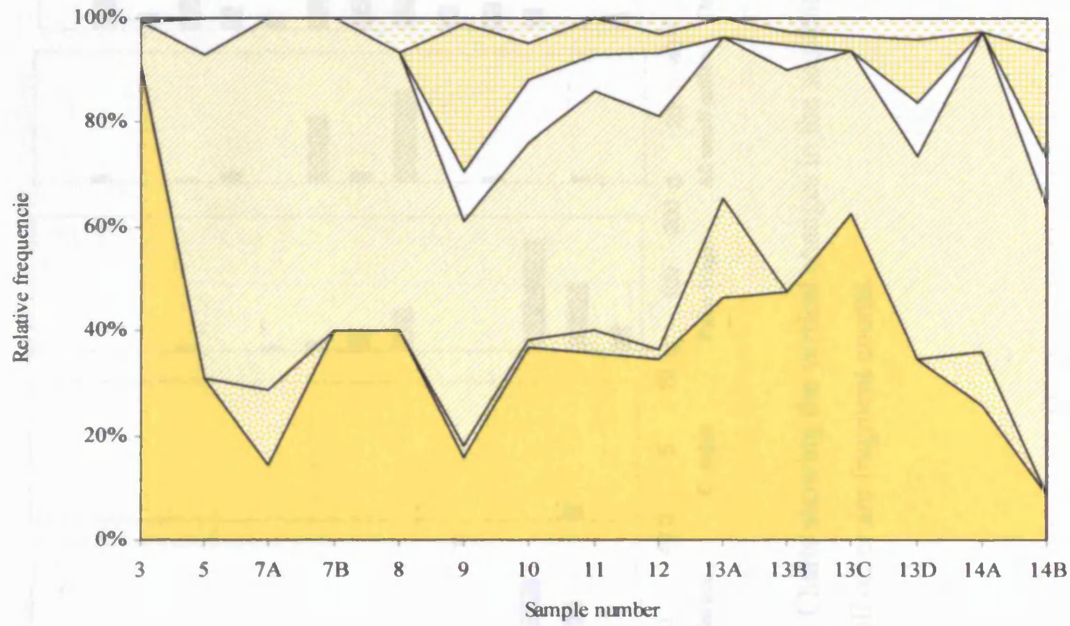


Figure 7.18: Bar chart of the relative frequencies of macro-remains from Golbai Sasan.

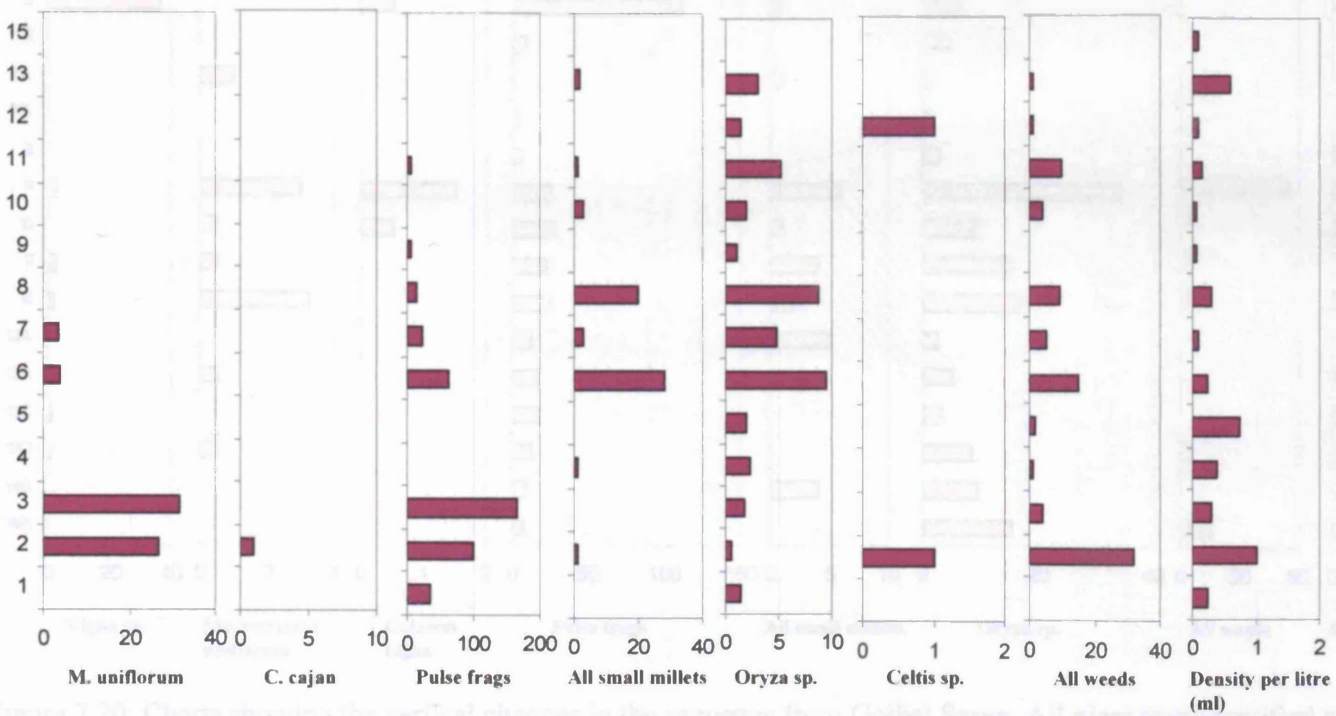


Figure 7.19: Charts showing the vertical changes in the sequence from Gopalpur. All plant taxa identified at least to genus are in absolute counts and all other are fragment counts.

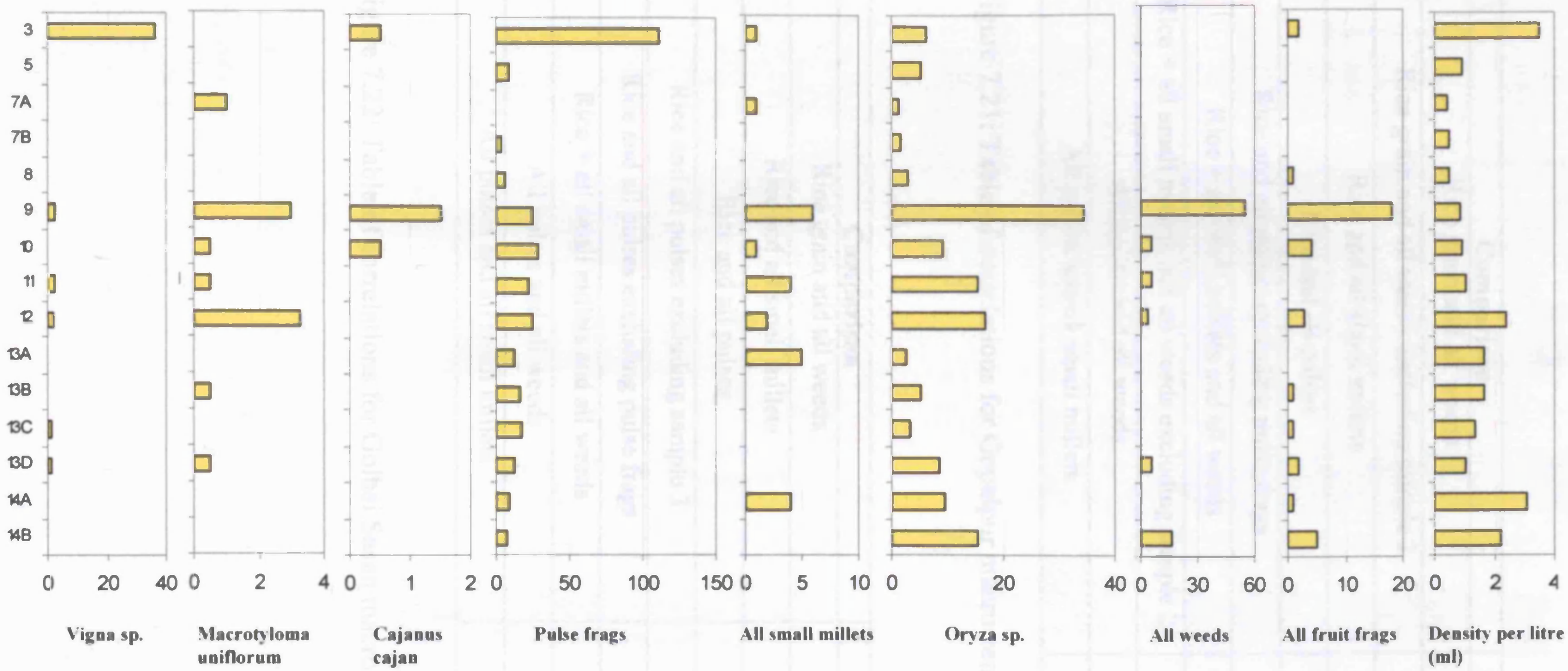


Figure 7.20: Charts showing the vertical changes in the sequence from Golbai Sasan. All plant taxa identified at least to genus are in absolute counts and all others are fragment counts. Each plant taxa has its own scale.

Comparison	R^2 value
Rice grain and all weeds	0.0536
Rice grain and all weeds excluding sample 2	0.8311
Rice and all small millets	0.793
Rice and all pulses	0.0037
Rice and all pulses excluding pulse frags	0.0423
Rice + all small millets and all weeds	0.0952
Rice + all small millets and all weeds excluding sample 2	0.7353
All pulses and all weeds	0.2445
All pulses and all small millets	0.0021

Figure 7.21: Table of correlations for Gopalpur macro-remains.

Comparison	R^2 value
Rice grain and all weeds	0.7795
Rice and all small millets	0.3483
Rice and all pulses	0.0102
Rice and all pulses excluding sample 3	0.4604
Rice and all pulses excluding pulse frags	0.0089
Rice + all small millets and all weeds	0.7399
All pulses and all weeds	0.0145
All pulses and all small millets	0.0023

Figure 7.22: Table of correlations for Golbai Sasan macro-remains.

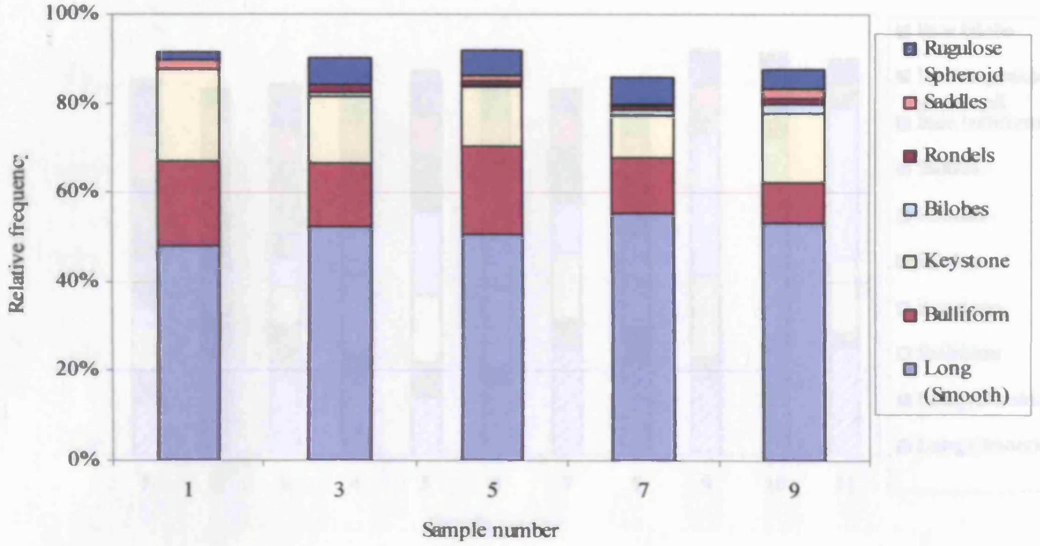


Figure 7.23: Graph showing the relative frequencies of single-celled phytoliths from Chopani-Mando.

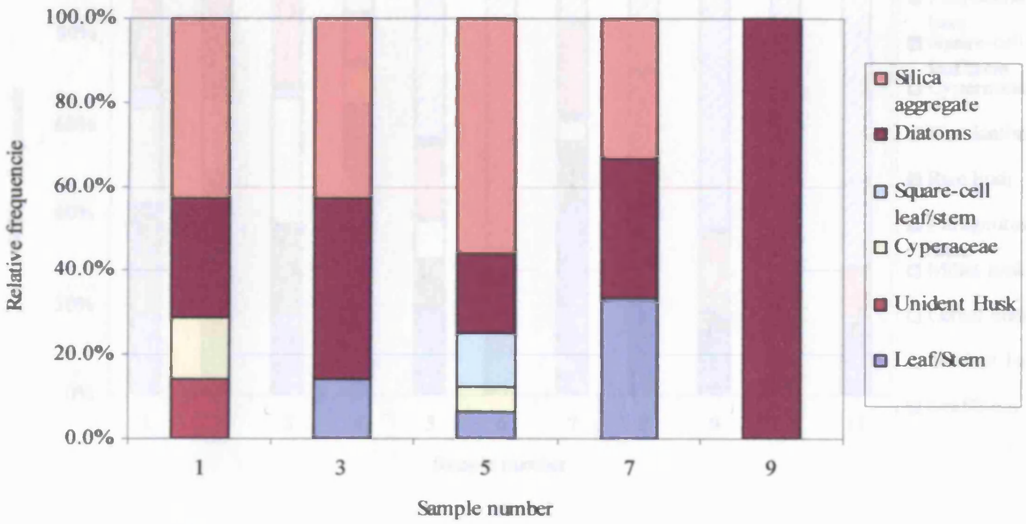


Figure 7.24: Graph showing the relative frequencies of multi-celled phytoliths from Chopani-Mando.

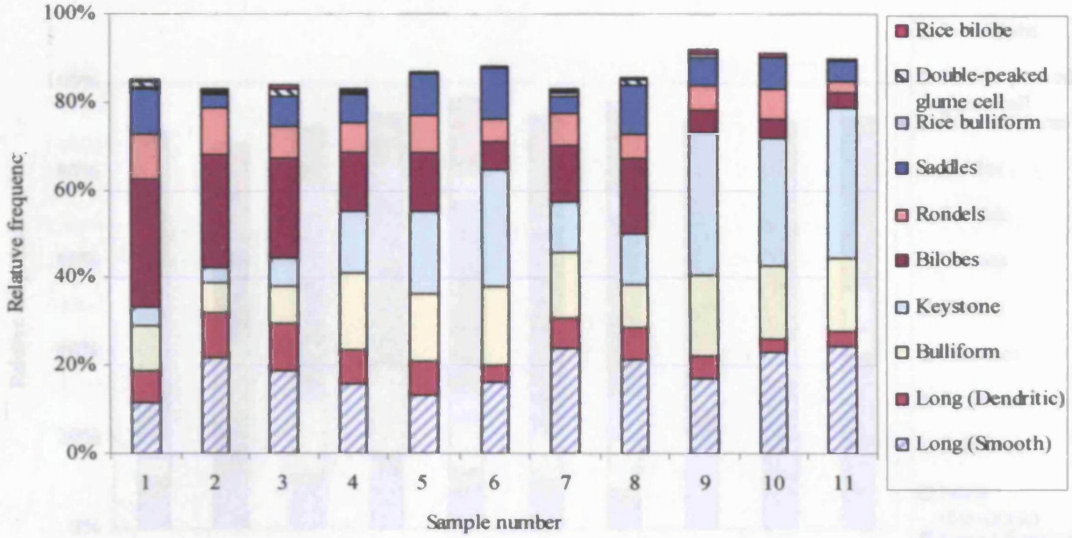


Figure 7.25: Graph showing the relative frequencies of single-celled phytoliths from Koldihwa.

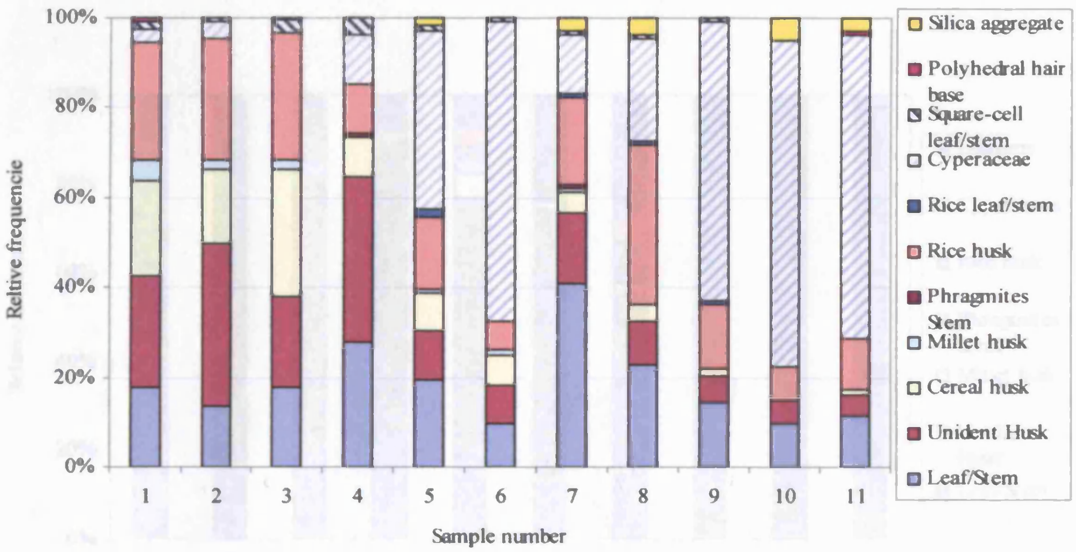


Figure 7.26: Graph showing the relative frequencies of multi-celled phytoliths from Koldihwa.

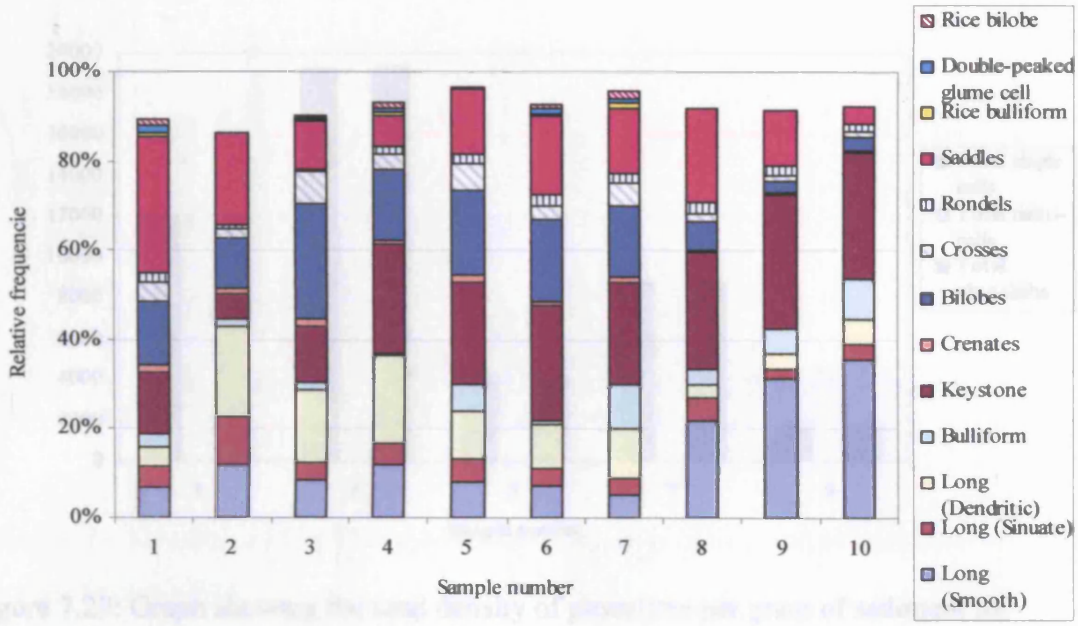


Figure 7.27: Graph showing the relative frequencies of single-celled phytoliths from Mahagara.

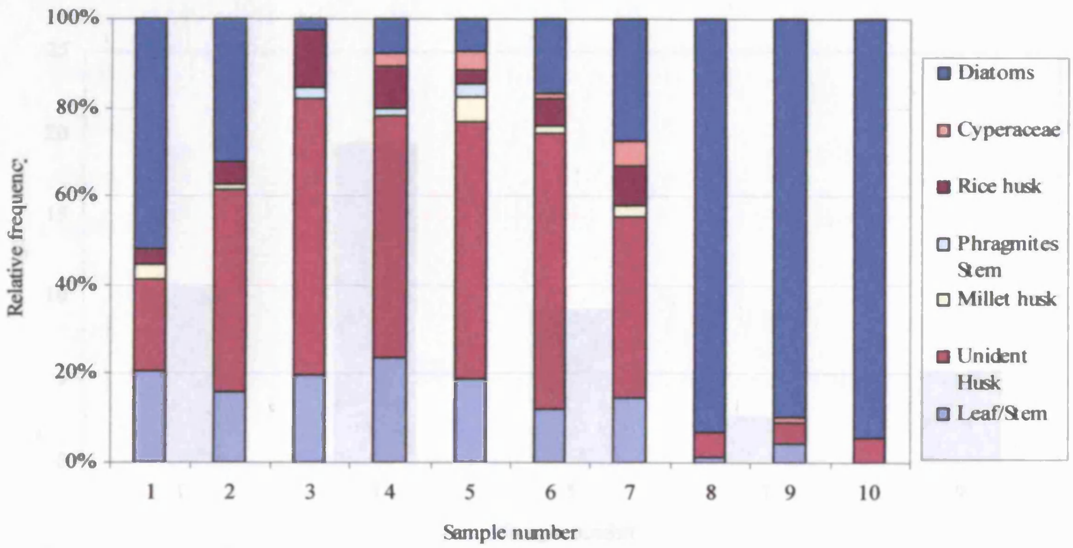


Figure 7.28: Graph showing the relative frequencies of multi-celled phytoliths from Mahagara.

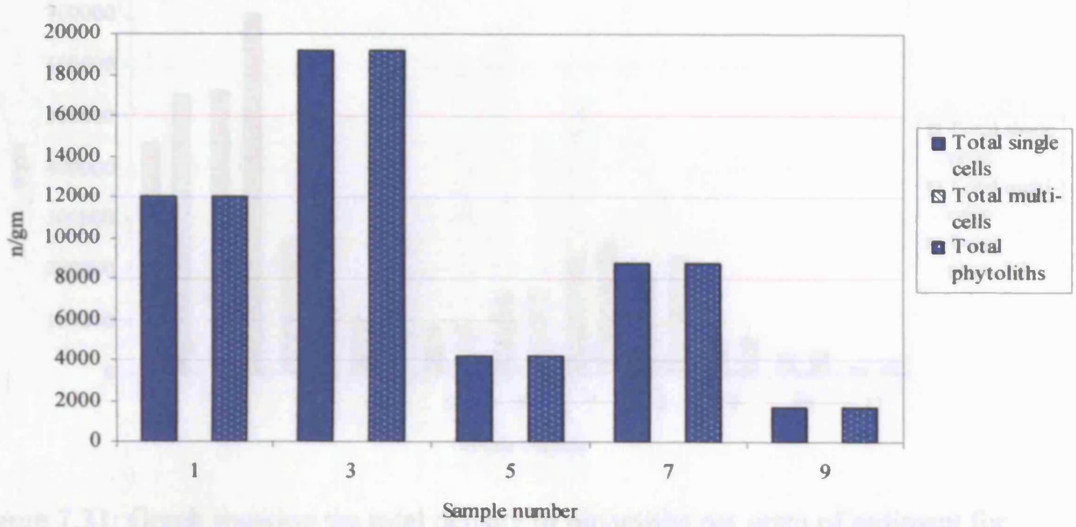


Figure 7.29: Graph showing the total density of phytoliths per gram of sediment for samples from Chopani-Mando.

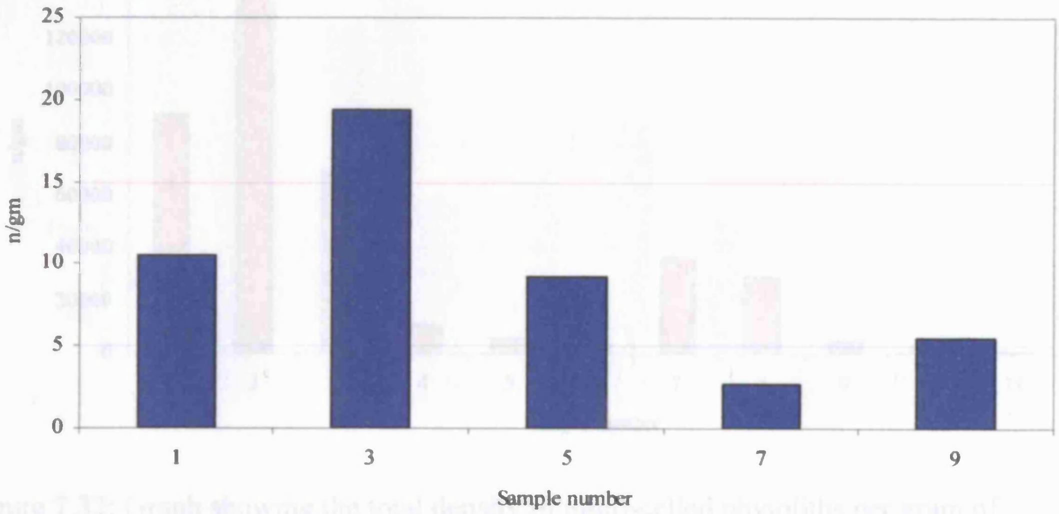


Figure 7.30: Graph showing the total density of multi-celled phytoliths per gram of sediment for sample from Chopani Mando.

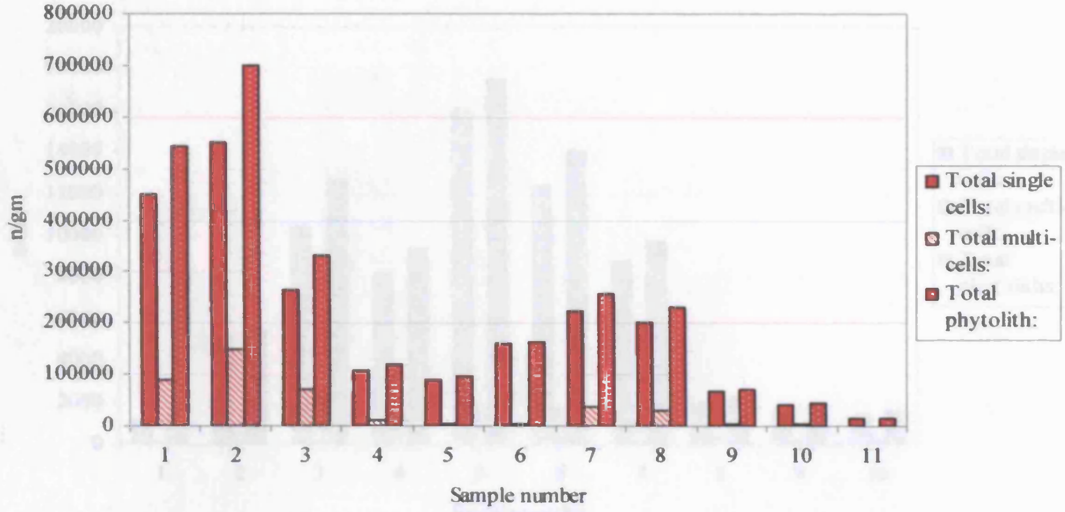


Figure 7.31: Graph showing the total density of phytoliths per gram of sediment for samples from Koldihwa.

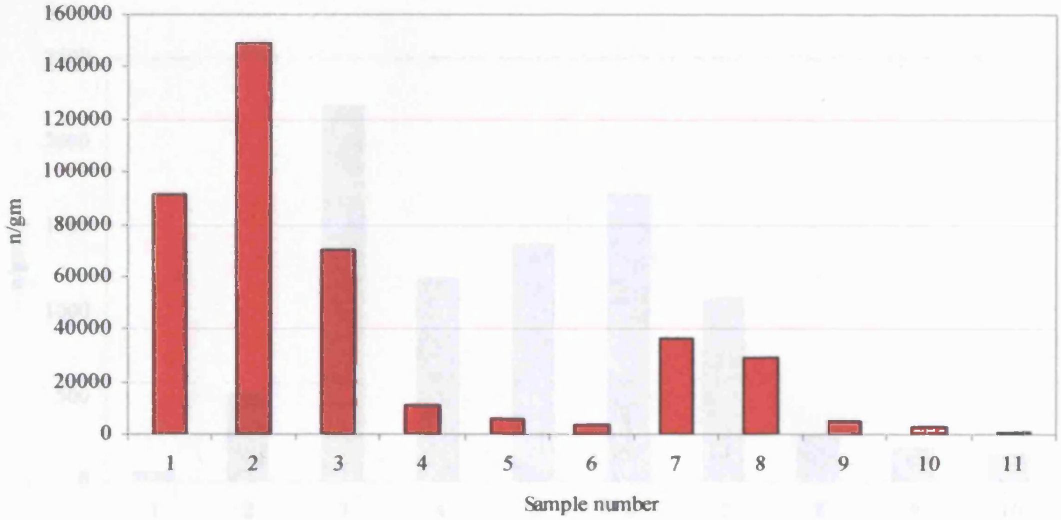


Figure 7.32: Graph showing the total density of multi-celled phytoliths per gram of sediment for sample from Koldihwa.

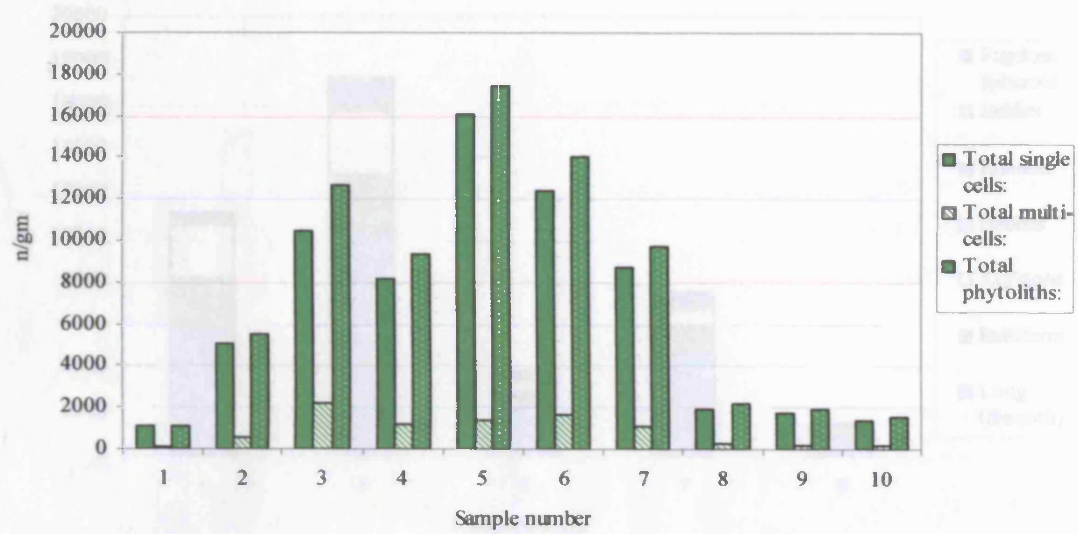


Figure 7.33: Graph showing the total density of phytoliths per gram of sediment for samples from Mahagara.

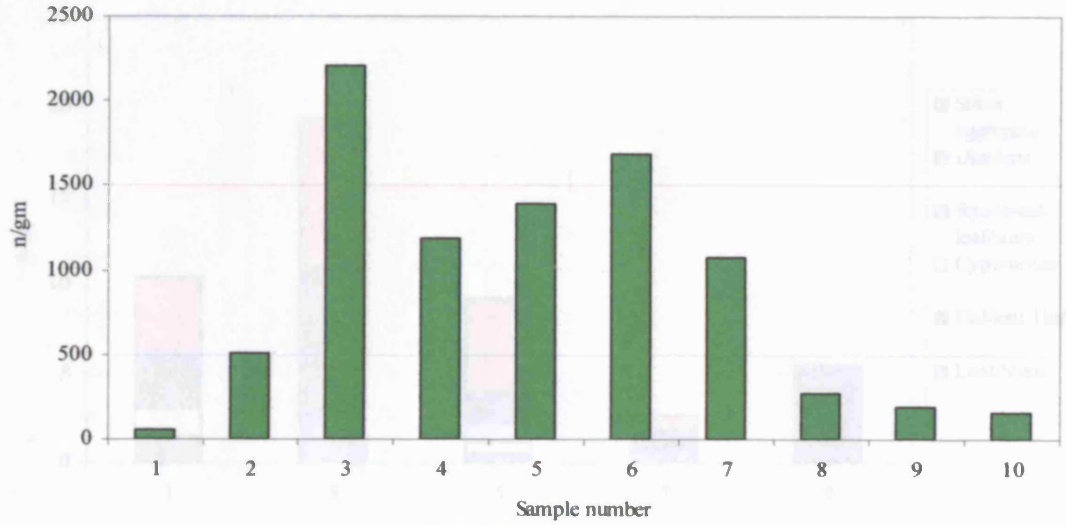


Figure 7.34: Graph showing the total density of multi-celled phytoliths per gram of sediment for sample from Mahagara.

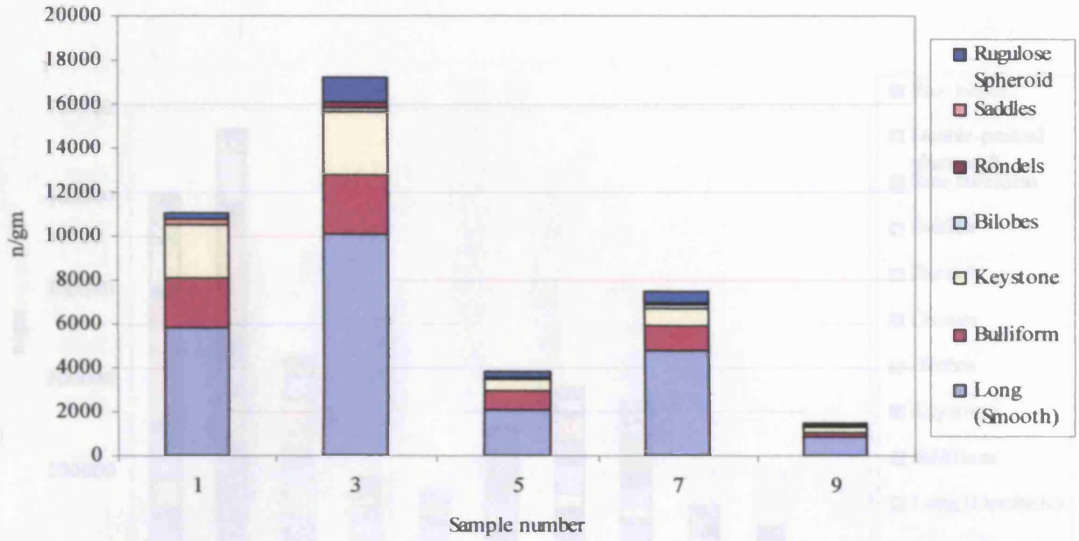


Figure 7.35: Graph showing the absolute density of single-celled phytoliths from Chopani-Mando.

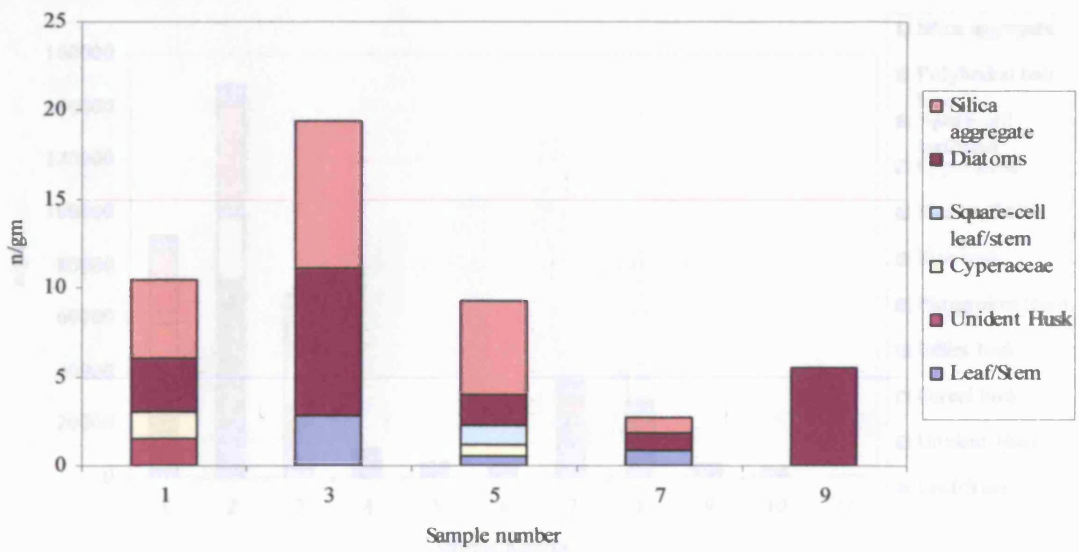


Figure 7.36: Graph showing the absolute density of multi-celled phytoliths from Chopani-Mando.

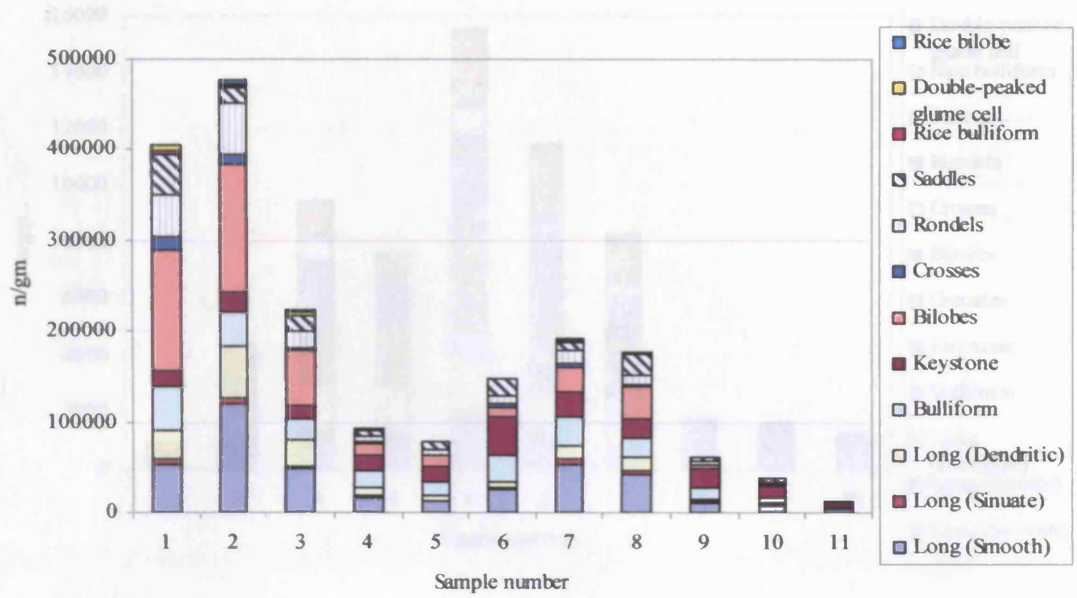


Figure 7.37: Graph showing the absolute density of single-celled phytoliths from Koldihwa.

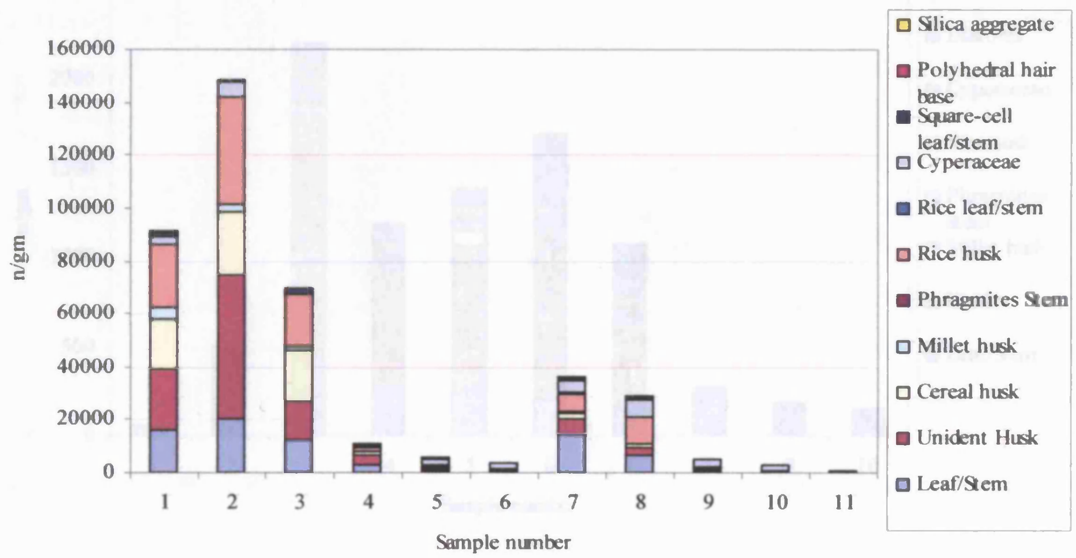


Figure 7.38: Graph showing the absolute density of multi-celled phytoliths from Koldihwa.

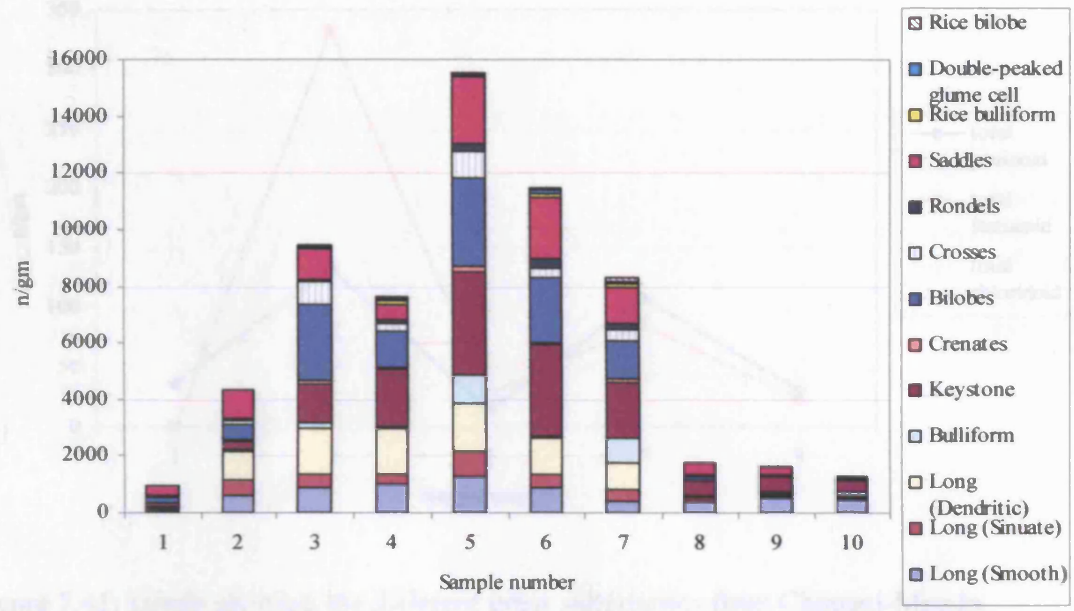


Figure 7.39: Graph showing the absolute density of single-celled phytoliths from Mahagara.

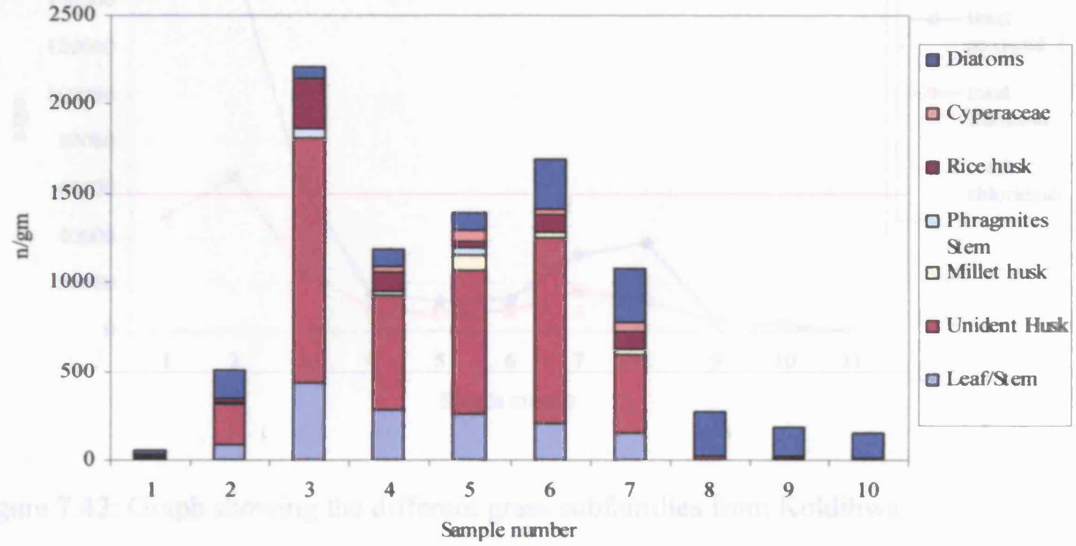


Figure 7.40: Graph showing the absolute density of multi-celled phytoliths from Mahagara.

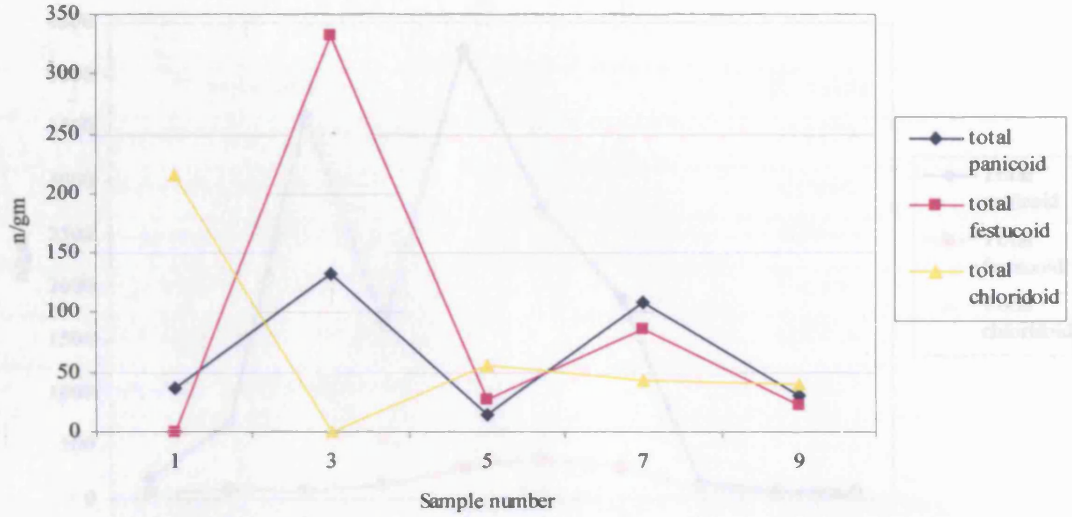


Figure 7.41: Graph showing the different grass subfamilies from Chopani-Mando.

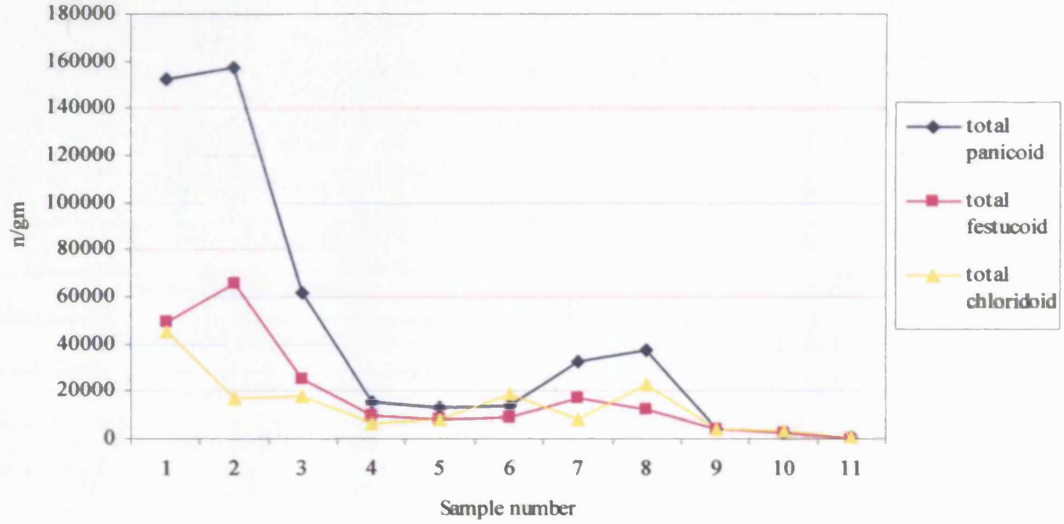


Figure 7.42: Graph showing the different grass subfamilies from Koldihwa.

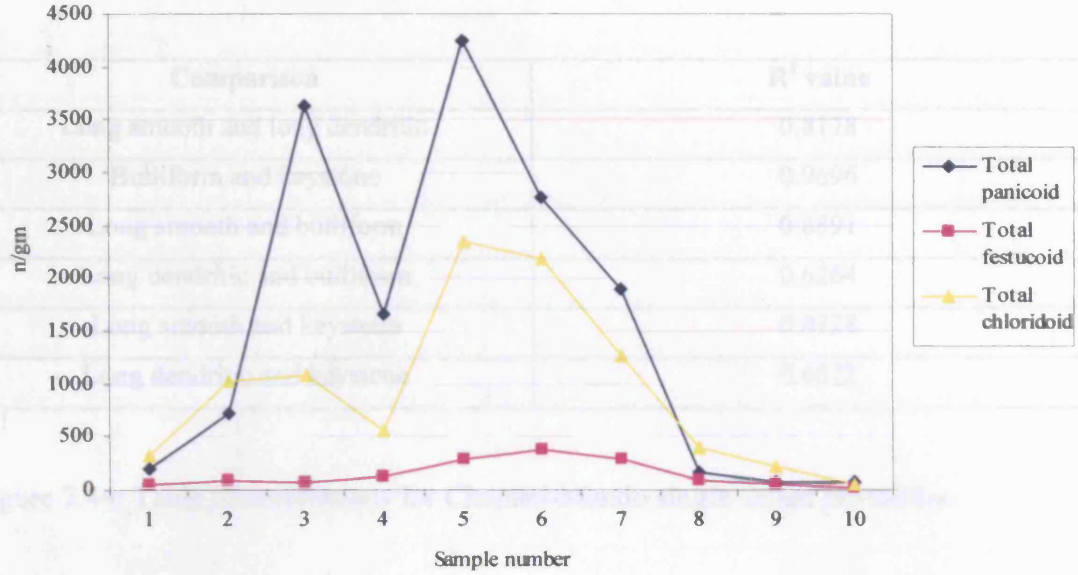


Figure 7.43: Graph showing the different grass subfamilies from Mahagara.

Comparison	R^2 value
Long smooth and long dendritic	0.8178
Bulliform and keystone	0.9696
Long smooth and bulliform	0.8891
Long dendritic and bulliform	0.6264
Long smooth and keystone	0.8328
Long dendritic and keystone	0.6572

Figure 7.44: Table of correlations for Chopani-Mando single-celled phytoliths.

Comparisons	R^2 value
Long smooth and long dendritic	0.9208
Bilobes and crosses	0.8456
Bilobes and rondels	0.9726
Bilobes and saddles	0.5509
Crosses and rondels	0.8415
Crosses and saddles	0.6633
Rondels and saddles	0.4568
Bilobes and long dendritic	0.8878
Bilobes and long smooth	0.7473
Bulliform and keystone	0.2265
Bulliform and long dendritic	0.5548
Saddles and long dendritic	0.3129
Saddles and long smooth	0.2188
Saddles and bulliform	0.6409
Saddles and keystone	0.0894

Figure 7.45: Table of comparisons for Koldihwa single-celled phytoliths.

Comparison	R^2 value
Long smooth and long dendritic	0.7091
Bilobes and crosses	0.9138
Bilobes and rondels	0.5801
Bilobes and saddles	0.7387
Crosses and rondels	0.4375
Crosses and saddles	0.6159
Rondels and saddles	0.8257
Bilobes and long dendritic	0.7977
Bilobes and long smooth	0.6548
Bulliform and keystone	0.4053
Bulliform and long dendritic	0.1933
Bulliform and long smooth	0.1586
Bulliform and crosses	0.5074
Bulliform and bilobes	0.3222
Bulliform and saddles	0.3822
Keystone and long dendritic	0.5507
Keystone and long smooth	0.6172
Keystone and bilobes	0.7338
Keystone and saddles	0.7755
Long smooth and crosses	0.5864
Long smooth and saddles	0.4535
Long smooth and rondels	0.4053
Long dendritic and crosses	0.701
Long dendritic and saddles	0.5251
Long dendritic and rondels	0.4012

Figure 7.46: Table of correlations for Mahagara single-celled phytoliths.

Comparison	R^2 values
Rice bulliform and double-peaked glume cell	0.416
Double-peaked glume cell and rice bilobe	0.44
Rice bulliforms and rice bilobe	0.2017
Rice husk and rice leaf/stem	0.0155
Rice husk and rice bulliform	0.2957
Rice husk and double-peaked glume cell	0.5655
Rice husk and rice bilobe	0.9499
Rice leaf/stem and rice bulliform	0.0642
Rice leaf/stem and double-peaked glume cell	0.0078
Rice leaf/stem and rice bilobe	0.0235
Rice husk and indet leaf/stem	0.8058
Rice husk and unident husk	0.9163
Rice leaf/stem and indet leaf/stem	0.0412
Rice leaf/stem and unident husk	0.0486
Rice husk and Cyperaceae	0.1497
Rice leaf/stem and Cyperaceae	0.3453

Figure 7.47: Table of correlations for Koldihwa multi-celled phytoliths.

Comparison	R^2 values
Rice bulliforms and double-peaked glume cell	0.57
Double-peaked glume cell and rice bilobe	0.4952
Rice bulliforms and rice bilobe	0.984
Rice husk and rice bulliform	0.4389
Rice husk and rice bulliforms without sample 2 and 3	0.9288
Rice husk and double-peaked glume cell	0.1625
Rice husk and double-peaked glume cell without sample 2 and 3	0.7134
Rice husk and rice bilobe	0.3678
Rice husk and rice bilobe without samples 2 and 3	0.8967
Rice husk and indet leaf/stem	0.8092
Rice husk and unident husk	0.7654
Rice bulliforms and indet leaf/stem	0.4785
Rice bulliform and unident husk	0.4505
Double-peaked glume cell and indet leaf/stem	0.2258
Double-peaked glume cell and unident husk	0.4087
Rice bilobe and indet leaf/stem	0.403
Rice bilobe and unident husk	0.3438
Rice husk and millet husk	0.001
Rice bulliforms and millet husk	0.0794
Double-peaked glume cell and millet husk	0.1146
Rice bilobe and millet husk	0.057

Figure 7.48: Table of correlations from Mahagara multi-celled phytoliths.

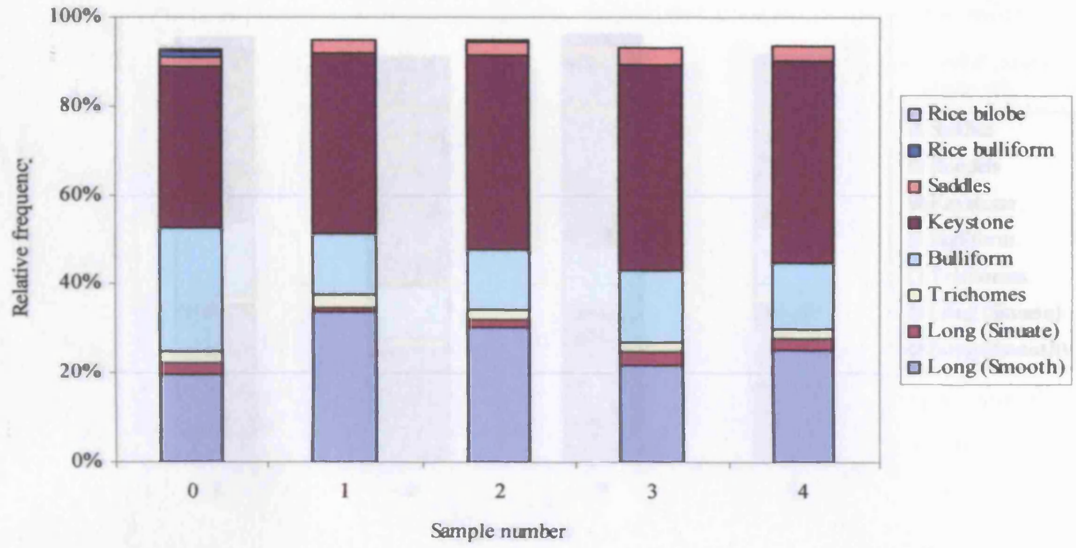


Figure 7.49: Graph showing the relative frequencies of single-celled phytoliths from Bajpur.

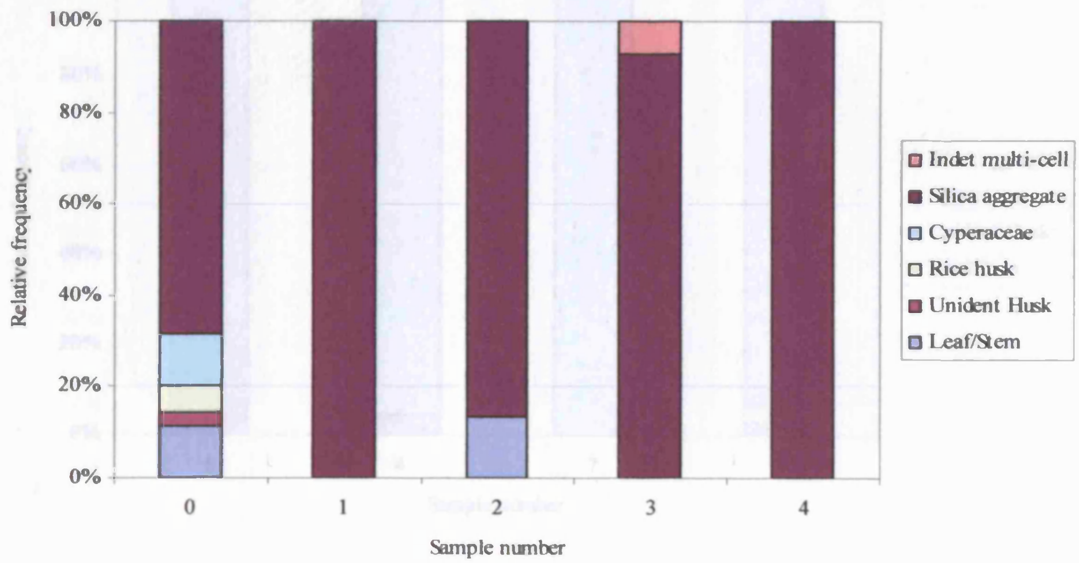


Figure 7.50: Graph showing the relative frequencies of multi-celled phytoliths from Bajpur.

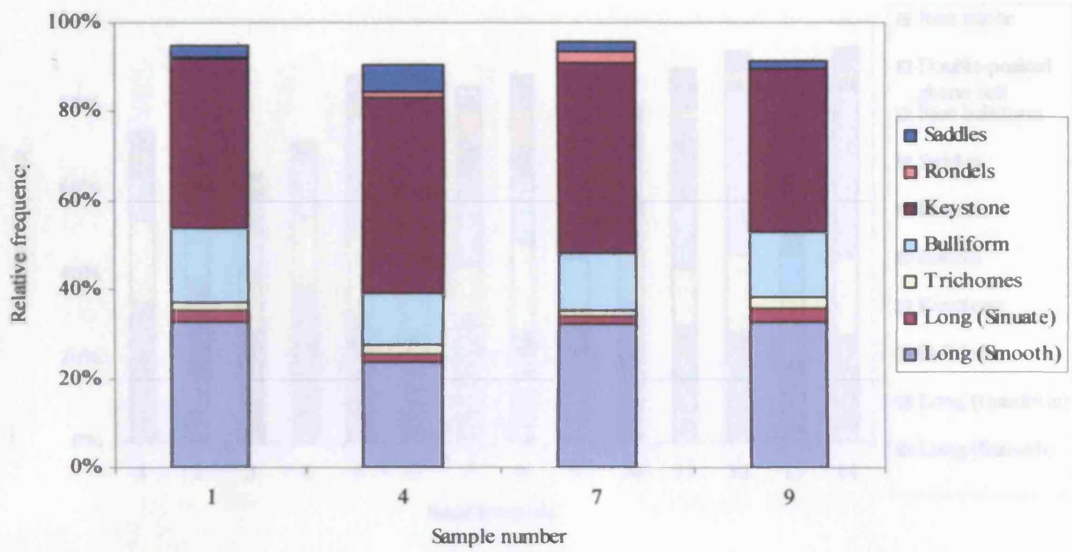


Figure 7.51: Graph showing the relative frequencies of single-celled phytoliths from Malakhoja.

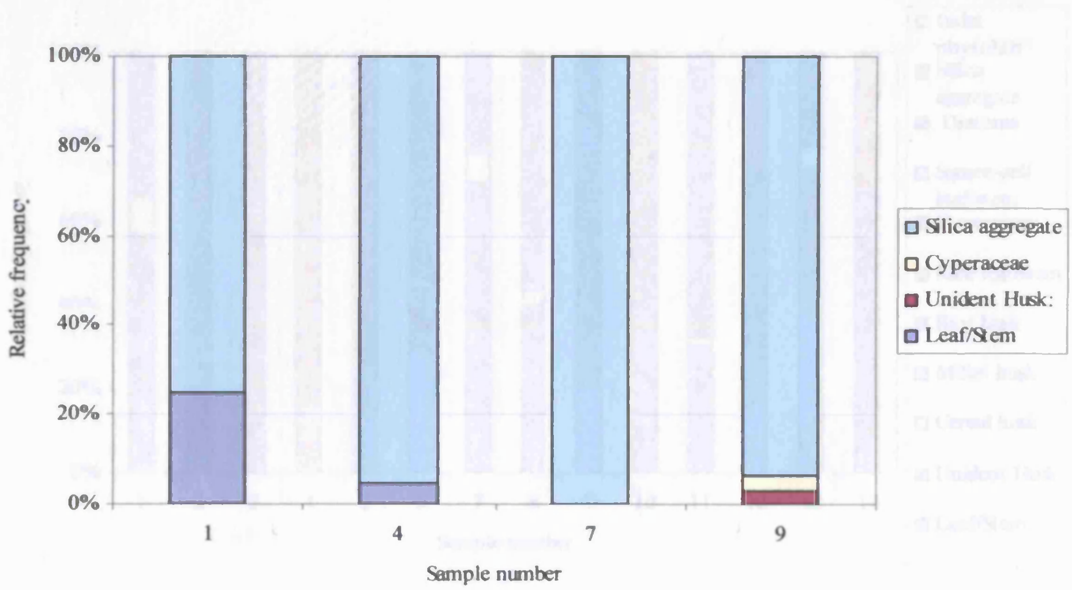


Figure 7.52: Graph showing the relative frequencies of multi-celled phytoliths from Malakhoja.

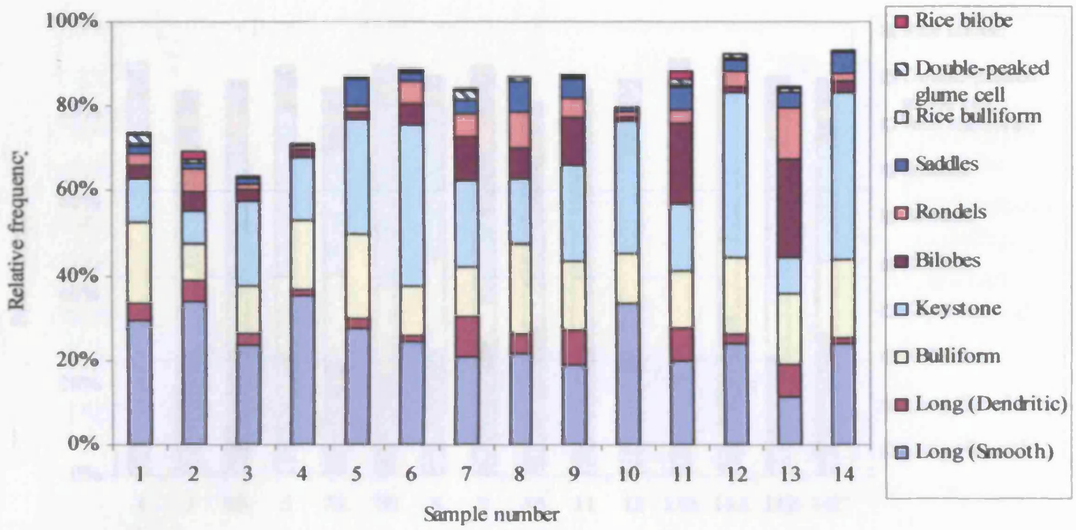


Figure 7.53: Graph showing the relative frequencies of single-celled phytoliths from Gopalpur.

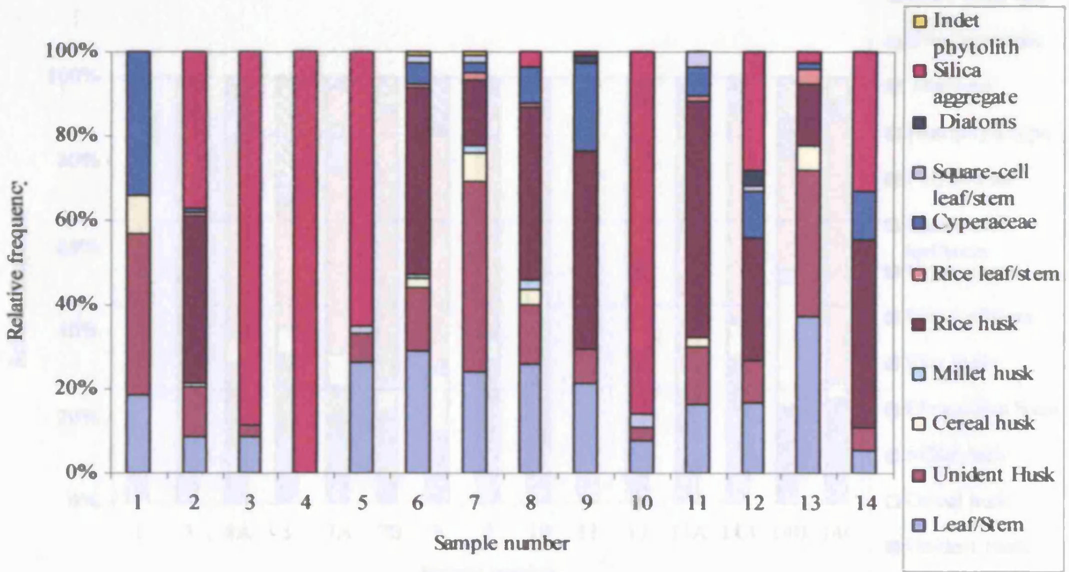


Figure 7.54: Graph showing the relative frequencies of multi-celled phytoliths from Gopalpur.

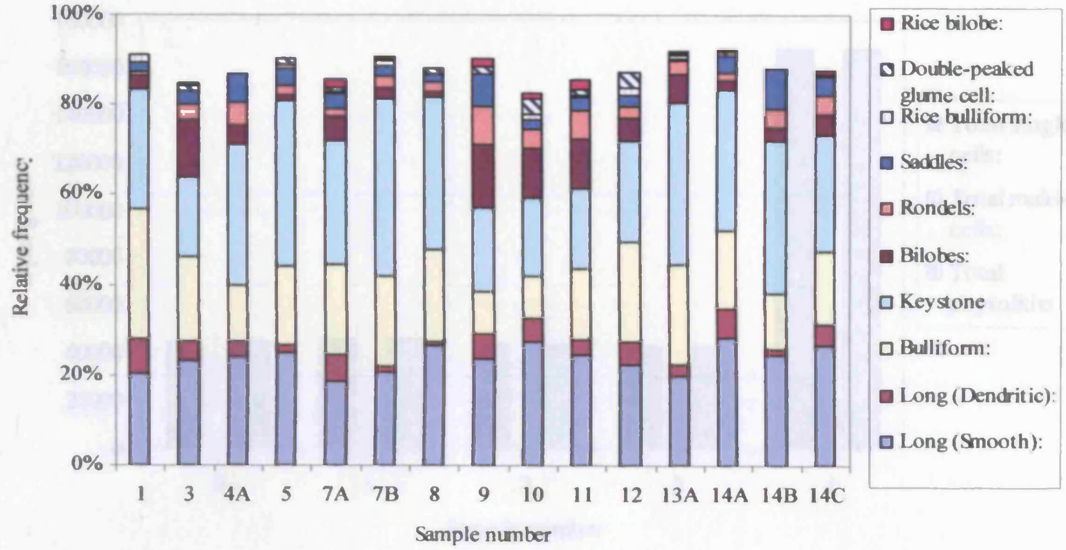


Figure 7.55: Graph showing the relative frequencies of single-celled phytoliths from Golbai Sasan.

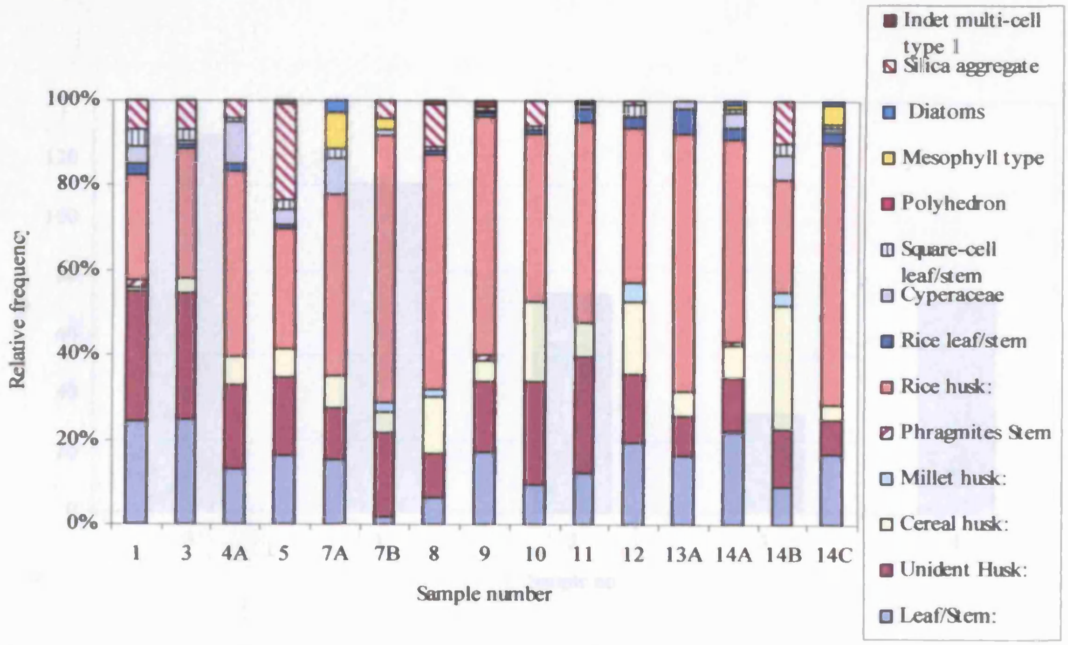


Figure 7.56: Graph showing the relative frequencies of multi-celled phytoliths from Golbai Sasan.

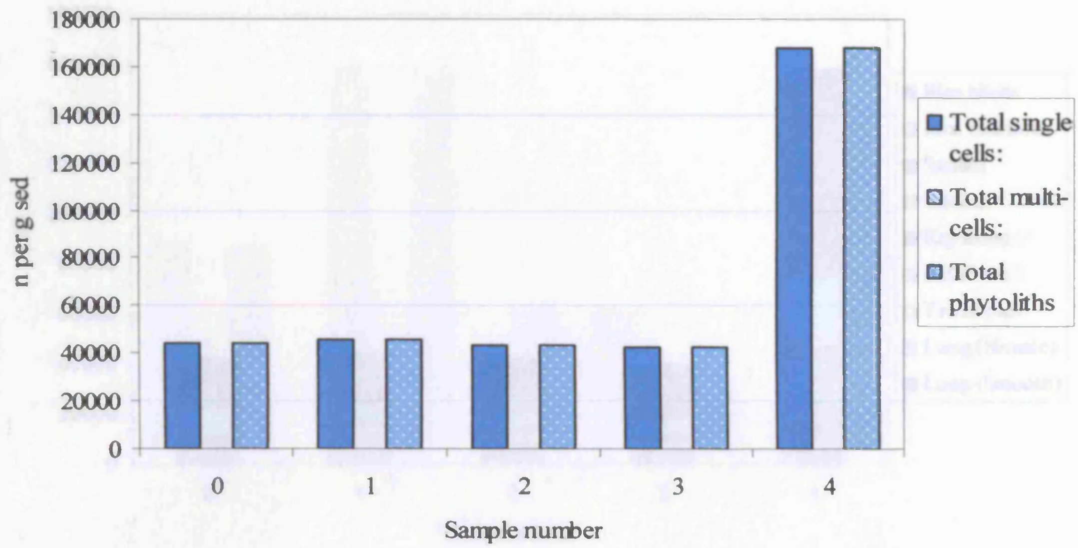


Figure 7.57: Graph showing the total density of phytoliths per gram of sediment for samples from Bajpur.

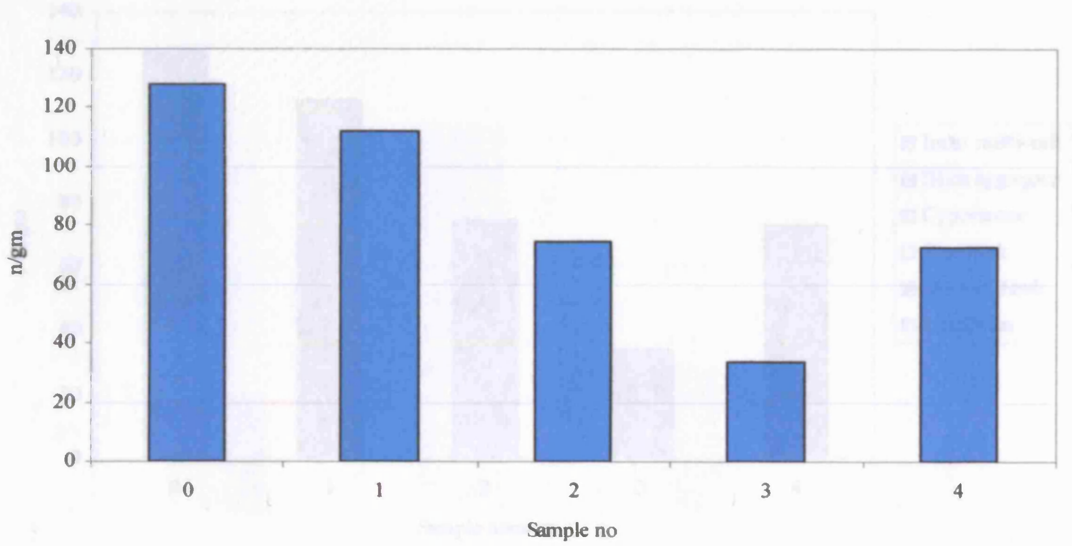


Figure 7.58: Graph showing the total density of multi-celled phytoliths per gram of sediment from Bajpur.

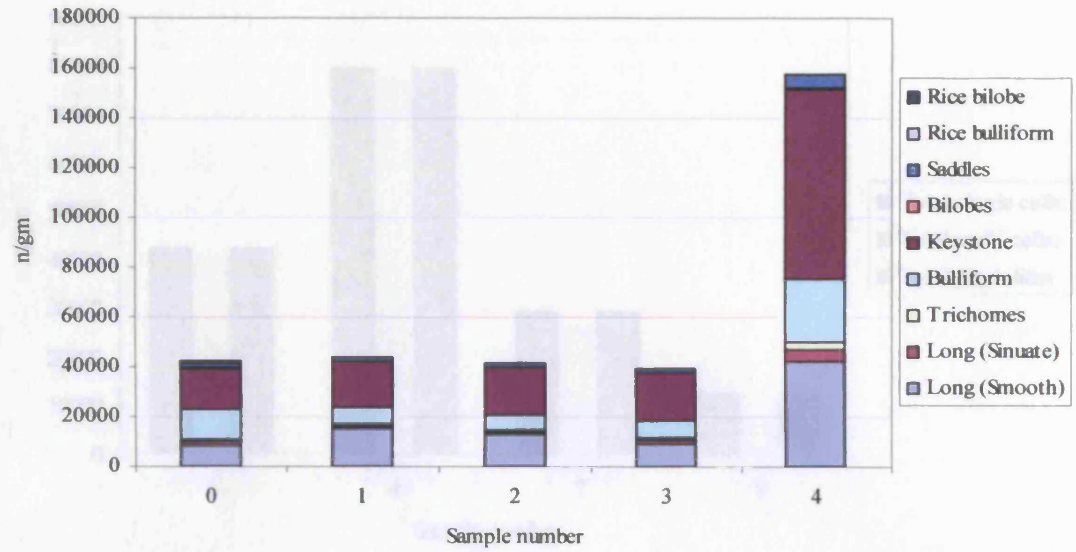


Figure 7.59: Graph showing the absolute density for single-celled phytoliths from Bajpur.

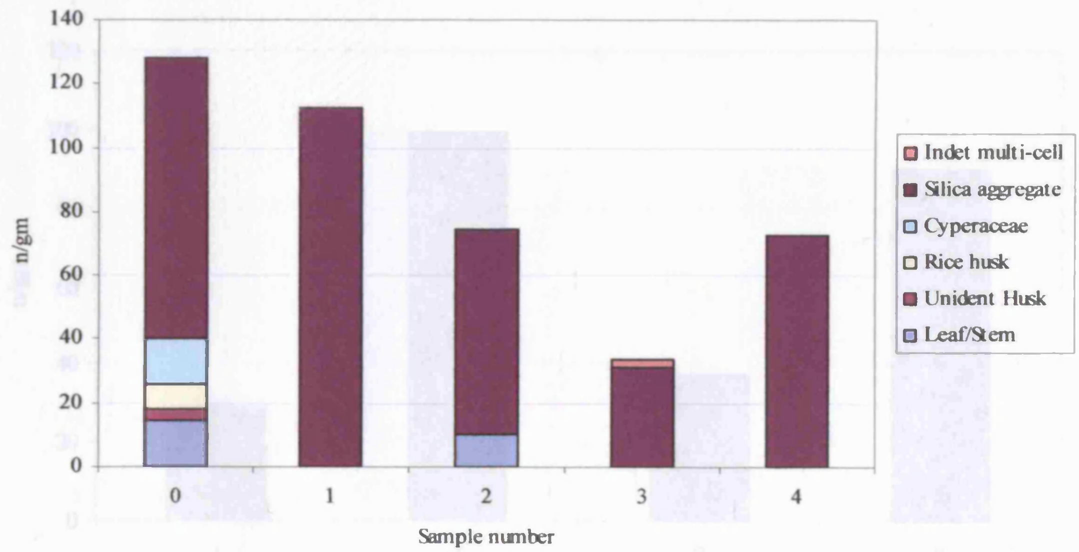


Figure 7.60: Graph showing the absolute density for multi-celled phytoliths from Bajpur.

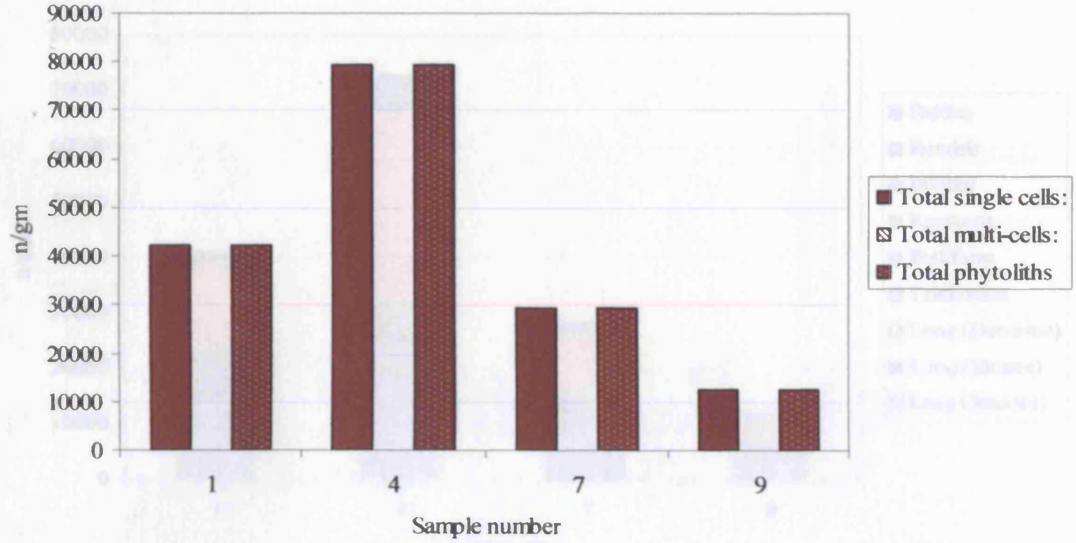


Figure 7.61: Graph showing the total density of phytoliths per gram of sediment for samples from Malakhoja.

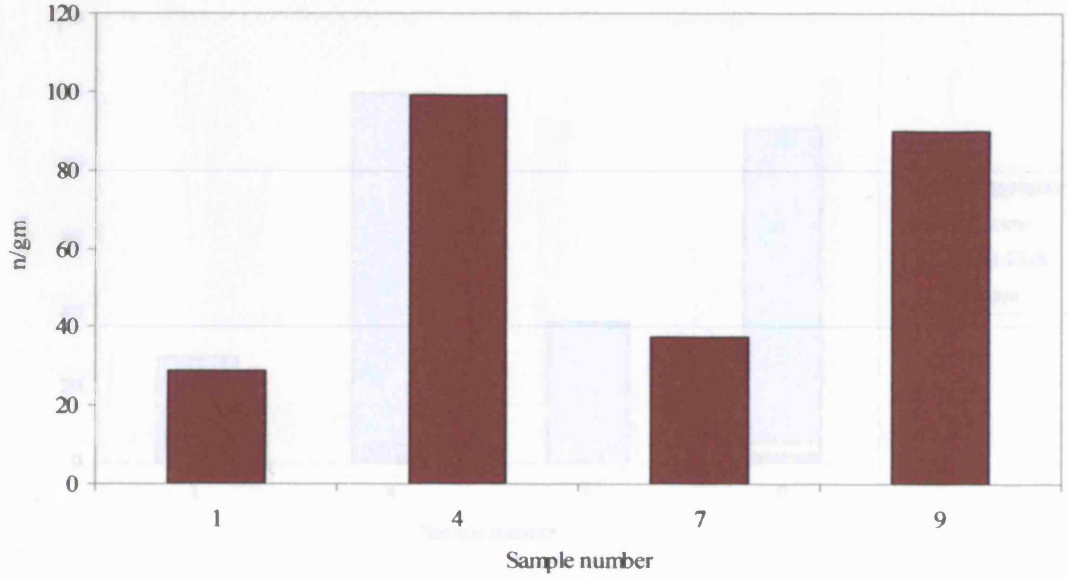


Figure 7.62: Graph showing the total density of multi-celled phytoliths per gram of sediment from Malakhoja.

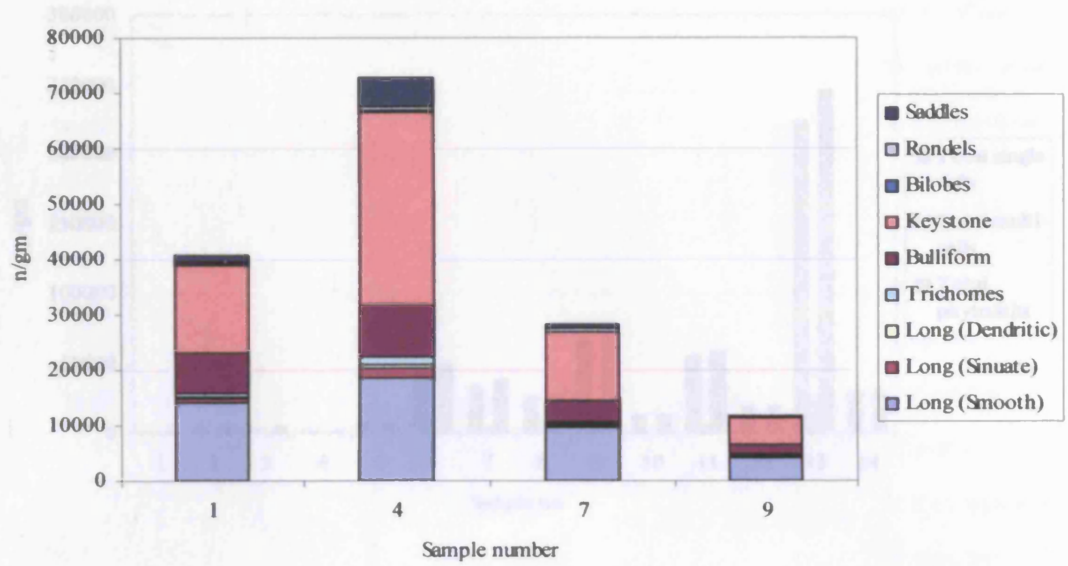


Figure 7.63: Graph showing the absolute density of single-celled phytoliths from Malakhoja.

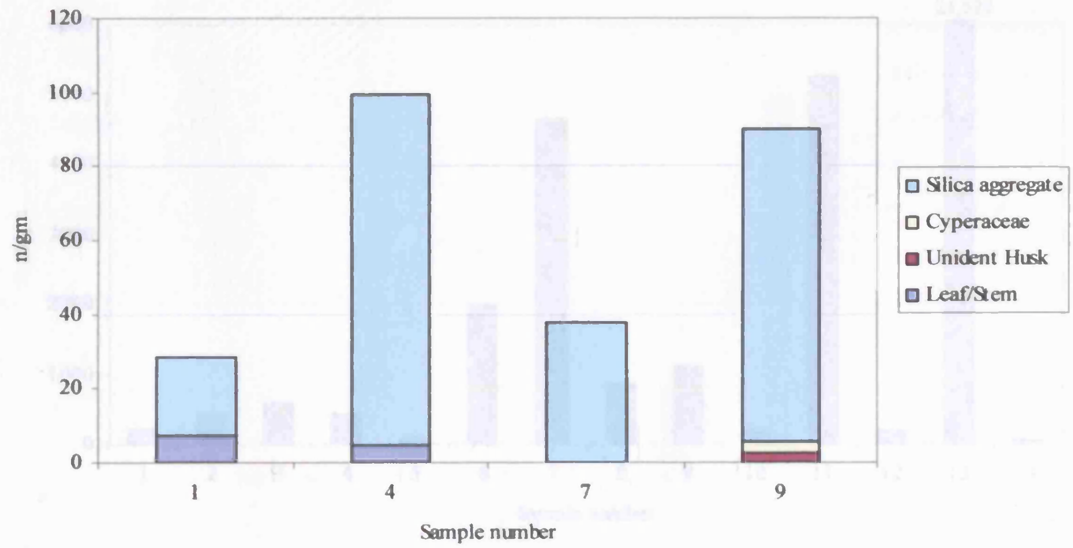


Figure 7.64: Graph showing the absolute density of multi-celled phytoliths from Malakhoja.

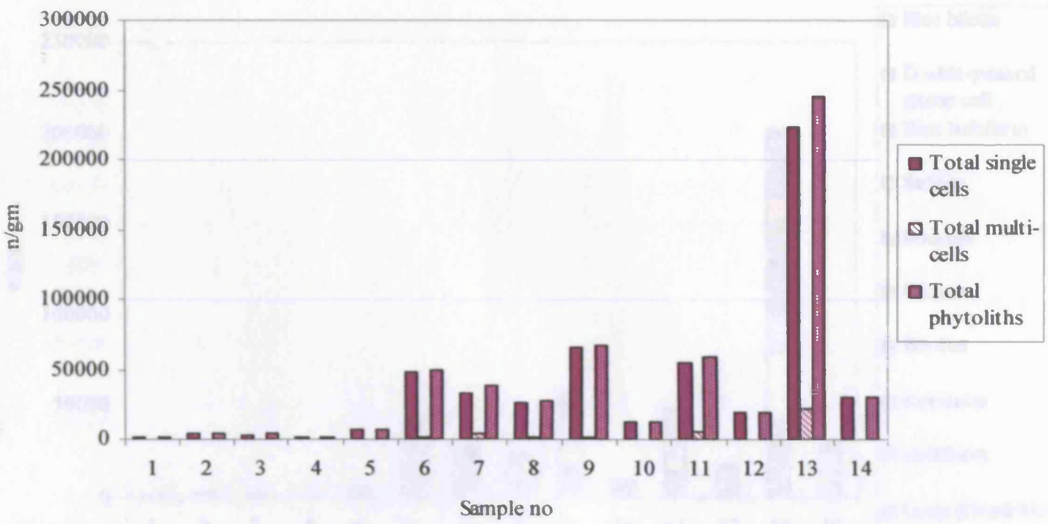


Figure 7.65: Graph showing the total density of phytoliths per gram of sediment for samples from Gopalpur.

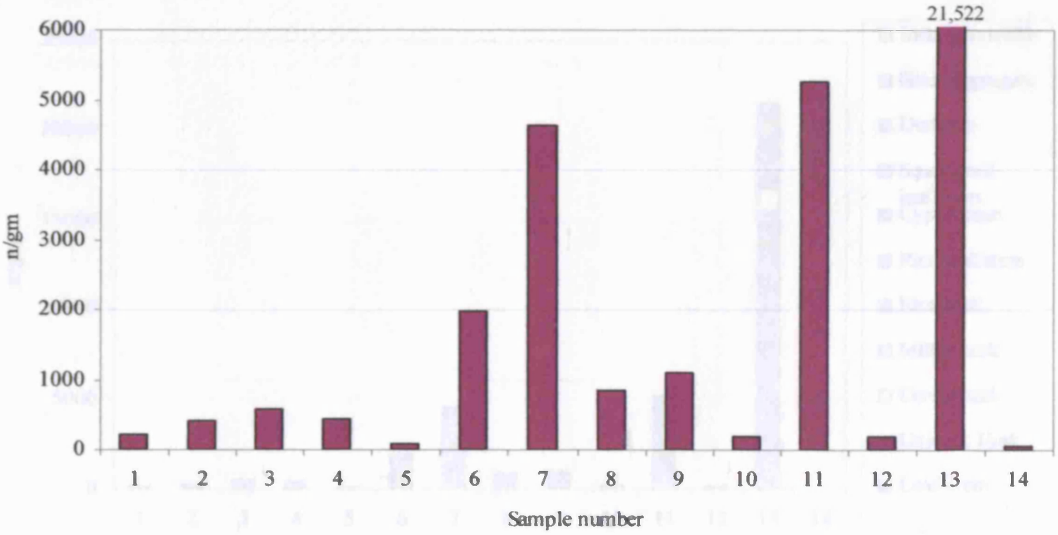


Figure 7.66: Graph showing the total density of multi-celled phytoliths per gram of sediment from Gopalpur.

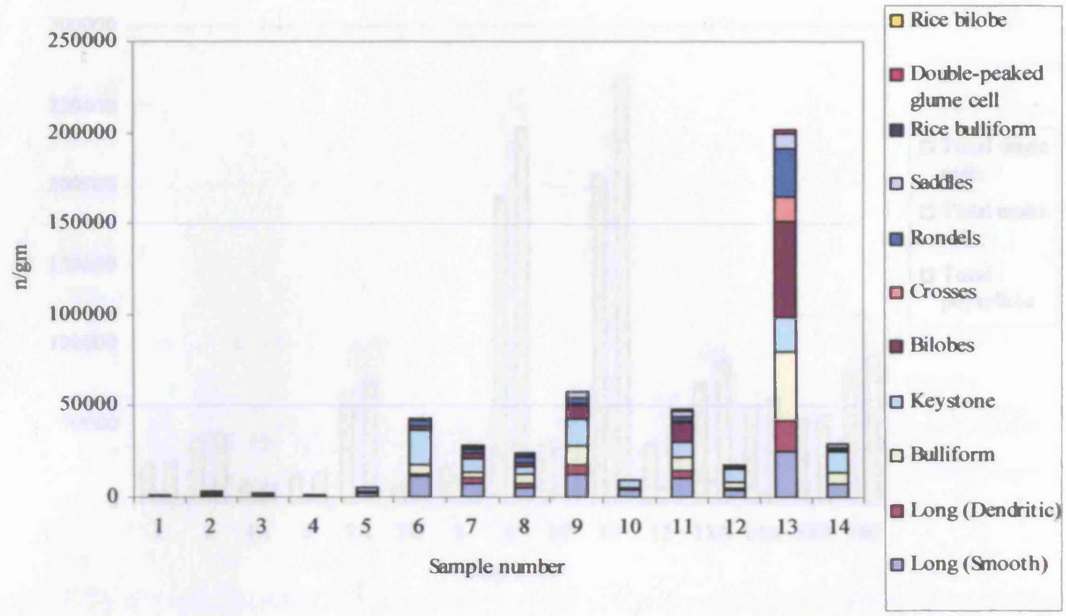


Figure 7.67: Graph showing the absolute density of single-celled phytoliths from Gopalpur.

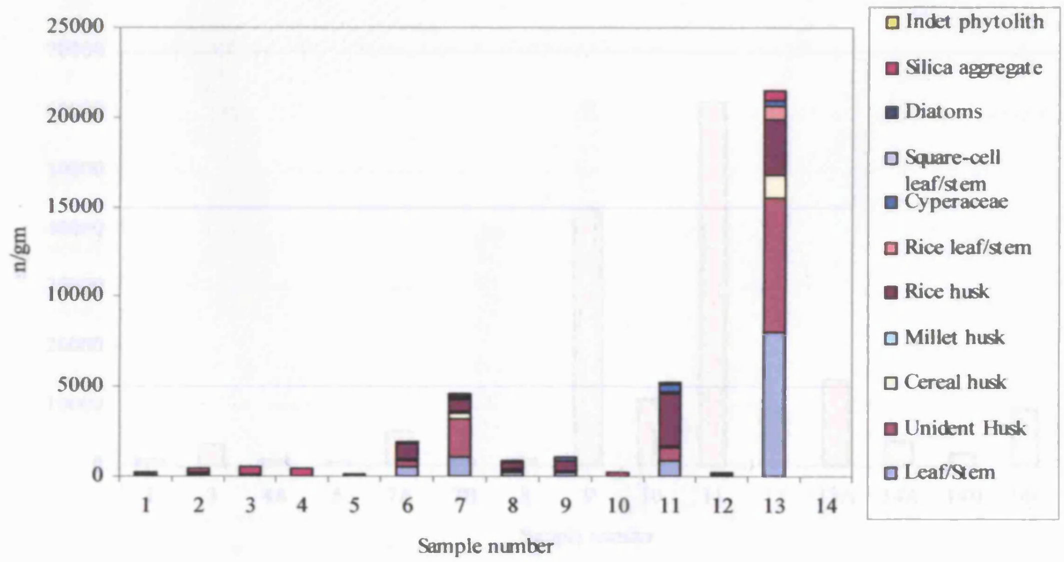


Figure 7.68: Graph showing the absolute density of multi-celled phytoliths from Gopalpur.

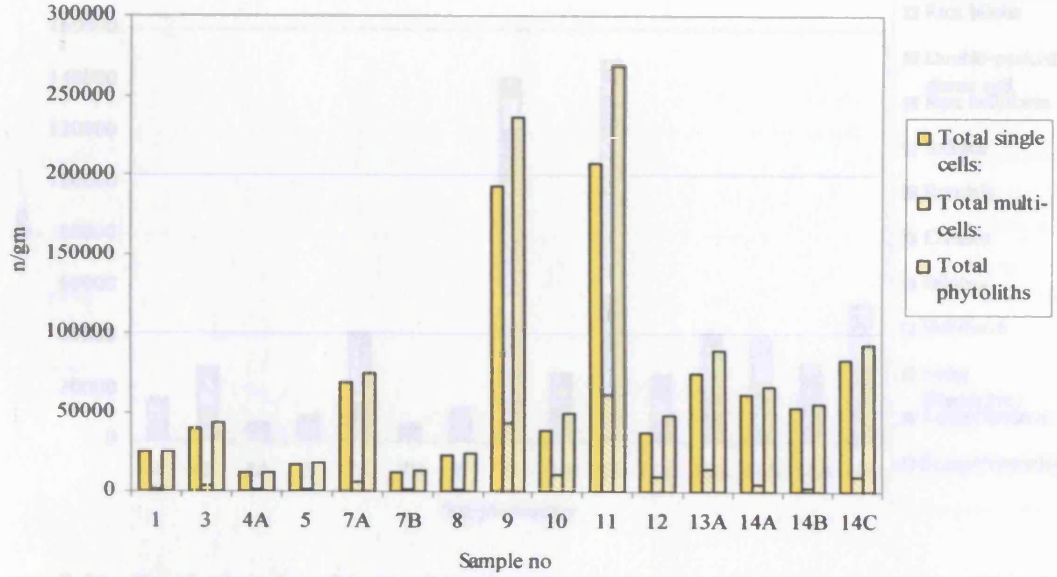


Figure 7.69: Graph showing the total density of phytoliths per gram of sediment for samples from Golbai Sasan.

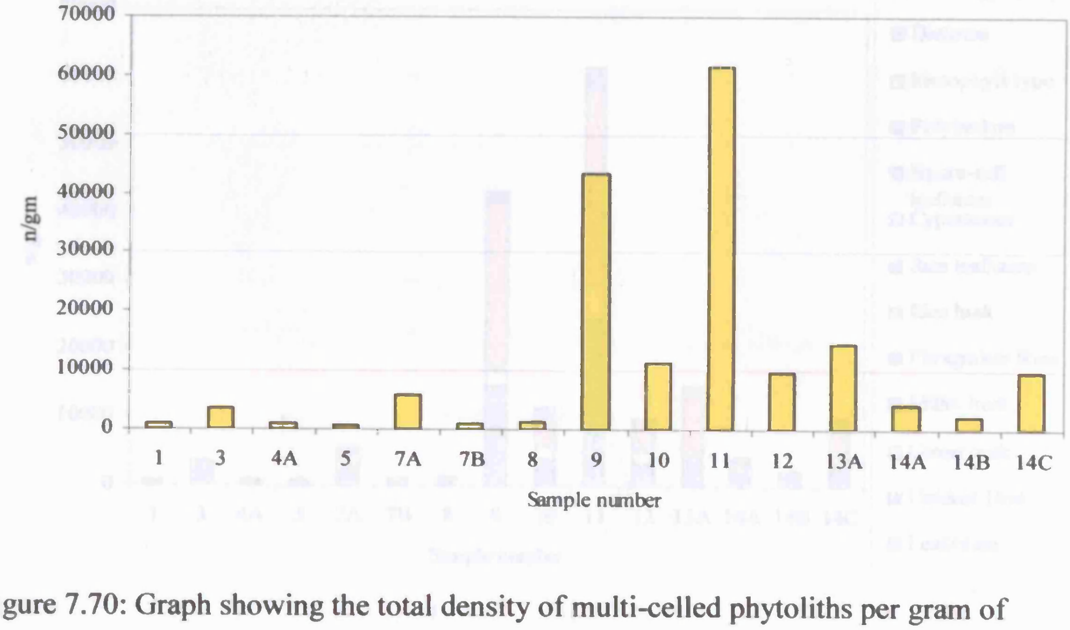


Figure 7.70: Graph showing the total density of multi-celled phytoliths per gram of sediment from Golbai Sasan.

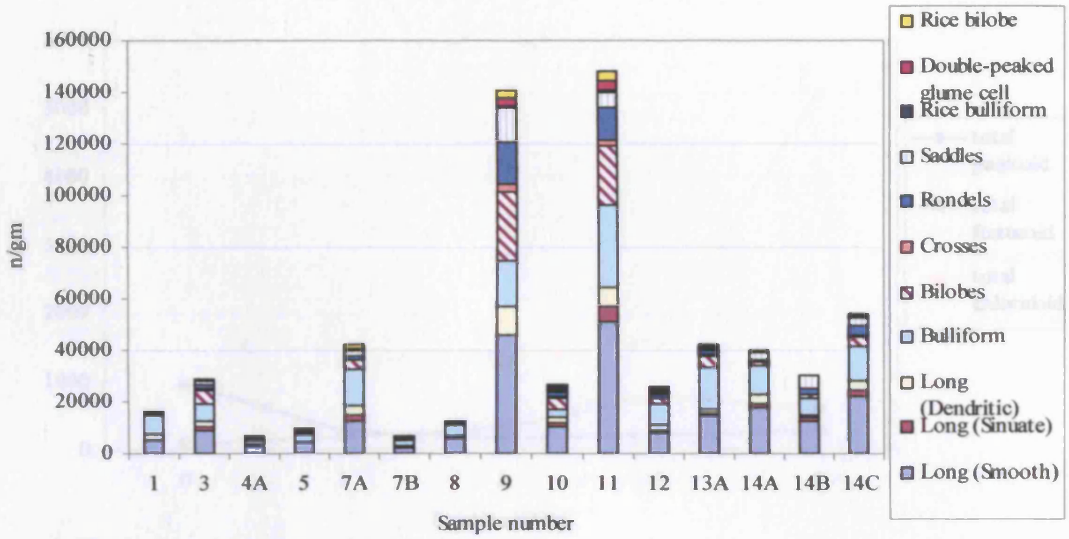


Figure 7.71: Graph showing the absolute density of single-celled phytoliths from Golbai Sasan.

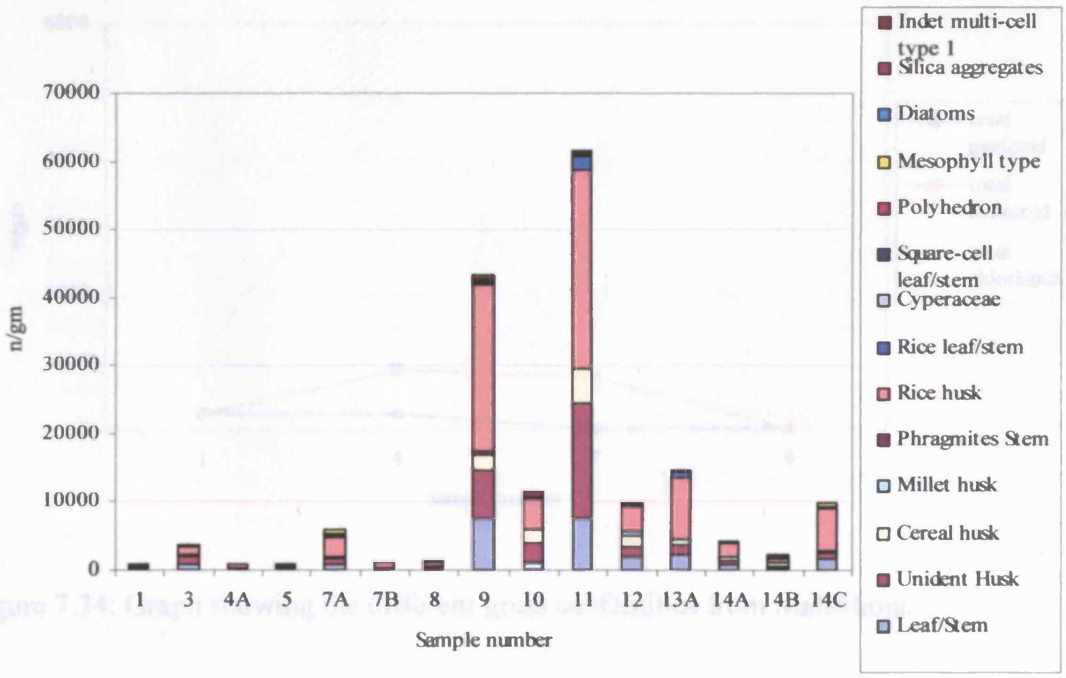


Figure 7.72: Graph showing the absolute density of multi-celled phytoliths from Golbai Sasan.

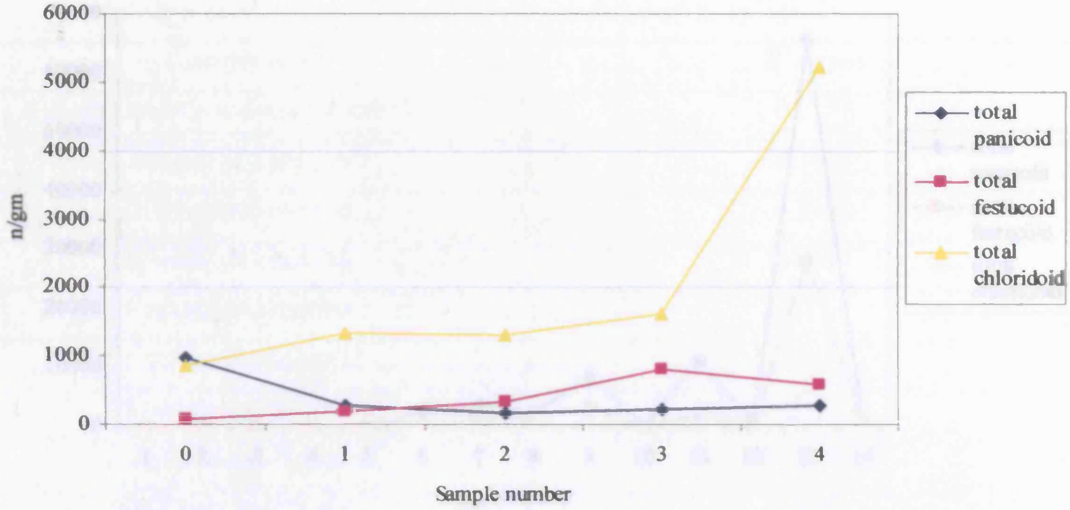


Figure 7.73: Graph showing the different grass subfamilies from Bajpur.

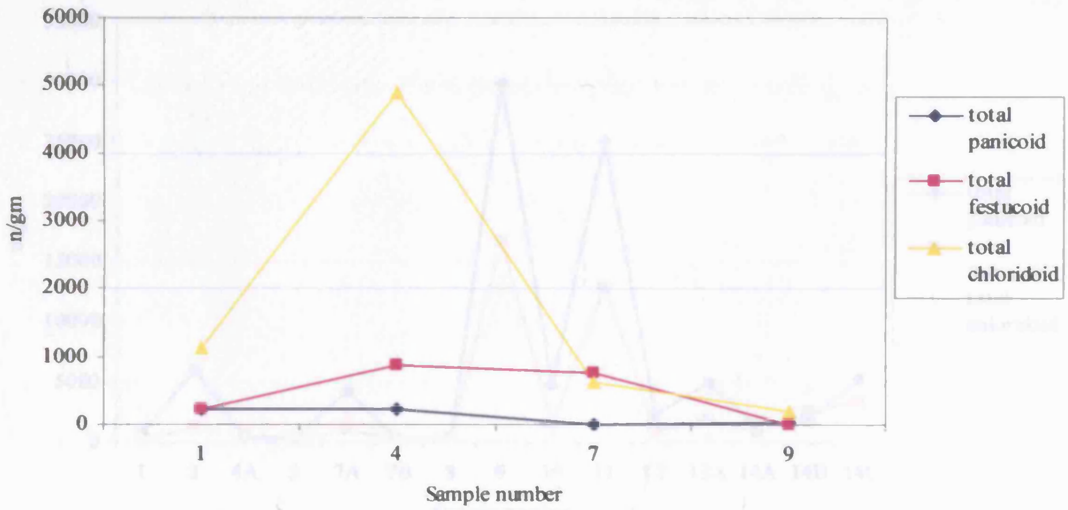


Figure 7.74: Graph showing the different grass subfamilies from Malakhoja.

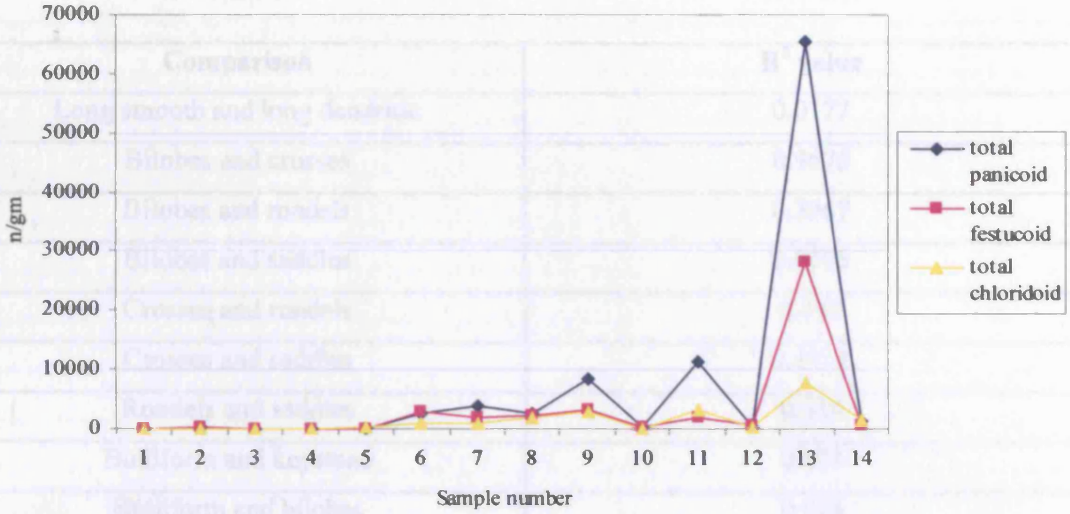


Figure 7.75: Graph showing the different grass subfamilies from Gopalpur.

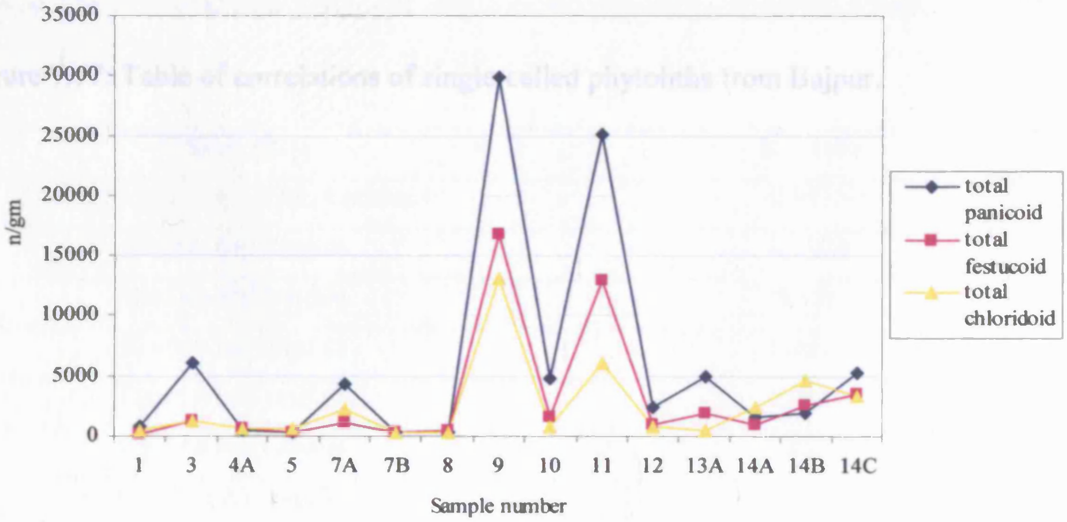


Figure 7.76: Graph showing the different grass subfamilies from Golbai Sasan.

Comparison	R^2 value
Long smooth and long dendritic	0.0177
Bilobes and crosses	0.9676
Bilobes and rondels	0.3967
Bilobes and saddles	0.0793
Crosses and rondels	0.443
Crosses and saddles	0.1413
Rondels and saddles	0.334
Bulliform and keystone	0.874
Bulliform and bilobes	0.024
Keystone and bilobes	0.0411
Keystone and trichome	0.9671
Trichome and bulliform	0.9115
Trichomes and bilobes	0.0069

Figure 7.77: Table of correlations of single-celled phytoliths from Bajpur.

Comparison	R^2 value
Long smooth and long dendritic	0.8061
Bilobes and rondels	0.0114
Bilobes and saddles	0.4378
Rondels and saddles	0.4484
Bulliform and keystone	0.8687
Keystone and trichome	0.9665
Trichomes and bilobes	0.8988
Saddles and bulliforms	0.7458
Saddles and long smooth	0.7451
Saddles and long dendritic	0.9106
Saddles and keystone	0.9549
Long smooth and rondels	0.4376
Long smooth and bilobes	0.6632

Figure 7.78: Table of correlations of single-celled phytoliths from Malakhoja.

Comparison	R^2 value
Long smooth and long dendritic	0.8113
Bilobes and crosses	0.9774
Bilobes and rondels	0.976
Bilobes and saddles	0.8975
Crosses and rondels	0.9884
Crosses and saddles	0.8276
Rondels and saddles	0.8389
Bulliform and keystone	0.5176
Keystone and trichome	0.767
Bulliform and bilobes	0.9571
Bilobes and keystone	0.3611
Bilobes and long smooth	0.7615
Bilobes and long dendritic	0.9672

Figure 7.79: Table of correlations of single-celled phytoliths from Gopalpur.

Comparison	R^2 value
Long smooth and long dendritic	0.8581
Bilobes and crosses	0.9637
Bilobes and rondels	0.9712
Bilobes and saddles	0.7636
Crosses and rondels	0.9252
Crosses and saddles	0.7791
Rondels and saddles	0.8562
Bulliform and keystone	0.8368
Keystone and trichome	0.7677
Bulliform and trichome	0.659
Bulliform and bilobes	0.6338
Bilobes and keystone	0.6678
Bilobes and long smooth	0.8902
Bilobes and long dendritic	0.852

Figure 7.80: Table of correlations of single-celled phytoliths from Golbai Sasan.

Comparison	R^2 values
Rice bulliform and double-peaked glume cell	0.5177
Double-peaked glume cell and rice bilobe	0.3645
Rice bulliforms and rice bilobe	0.1313
Rice husk and rice leaf/stem	0.5775
Rice husk and rice bulliform	0.4691
Rice husk and double-peaked glume cell	0.7366
Rice husk and rice bilobe	0.8005
Rice leaf/stem and rice bulliform	0.5344
Rice leaf/stem and double-peaked glume cell	0.8572
Rice leaf/stem and rice bilobe	0.224
Rice husk and indet leaf/stem	0.5749
Rice husk and unident husk	0.5474
Rice leaf/stem and indet leaf/stem	0.996
Rice leaf/stem and unident husk	0.9693
Rice husk and millet husk	0.005
Rice leaf/stem and millet husk	0.0003
Rice husk and cereal husk	0.562

Figure 7.81: Table of correlations for Gopalpur multi-celled phytoliths.

Comparison	R^2 values
Rice bulliform and double-peaked glume cell	0.3602
Double-peaked glume cell and rice bilobe	0.8346
Rice bulliforms and rice bilobe	0.3314
Rice husk and rice leaf/stem	0.6602
Rice husk and rice bulliform	0.3845
Rice husk and double-peaked glume cell	0.8665
Rice husk and rice bilobe	0.9167
Rice leaf/stem and rice bulliform	0.2807
Rice leaf/stem and double-peaked glume cell	0.4851
Rice leaf/stem and rice bilobe	0.5544
Rice husk and indet leaf/stem	0.9743
Rice husk and unident husk	0.8564
Rice leaf/stem and indet leaf/stem	0.5626
Rice leaf/stem and unident husk	0.7875
Rice husk and millet husk	0.0112
Rice husk and cereal husk	0.7469
Rice leaf/stem and millet husk	0.0009
Rice leaf/stem and cereal husk	0.716
Indet leaf/stem and unident husk	0.7841

Figure 7.82: Table of correlations for Golbai Sasan multi-celled phytoliths.

Mahagara and Koldihwa

Plant type	**No of genera or species in region**	**General habitats**
Chenopodiaceae	5 genera + 7 spp	Widely distributed, mainly in saline soils
Commelinaceae *Commelina benghalensis* (MGR)	4 genera	Found throughout India, up to 6000ft. Common in damp places Occurs from sea level to 1000m, best conditions are high soil moisture, and fertility, sunny and lightly shaded. Loamy, sandy, and rocky soils. Common weed of crops, grasslands, roadsides, and waster places.
Cyperaceae *Scirpus* type (MGR)	15 genera 12 spp of *Scirpus*	Plants of wet or marshy habitats 3 spp suggested as rice weeds, rest found in margins of pond and swampy habitats.
Euphorbiaceae	21 genera	Can be weeds of crop plants. Wet and dry condition species.
Gramineae *Eragrostis* sp. (MGR) *Ischaemum rugosum* (MGR)	 16 spp.	 Variety of environments – 3 dry species but other prefer wet conditions or edges of rivers. Common in pastures and can be a weed of crop plants. Common weed of rice fields, found throughout India. Annual.
Malvaceae	15 genera	Many species hold food products, are fibre plants, or are used medicinally.
Polygonaceae	2 genera	Most are wet loving species
Portulaceae	1 genera, 2 spp.	Pot herb and common weed of dry places

Figure 7.83: Tables of weeds present in the archaeobotanical assemblages and their environmental implications.

Gopalpur and Golbai Sasan

Plant type	**No genera/species**	**General habitats**
Aizoceae *Trianthamea* sp. (GBSN)	2 genera 1 spp. *T. monogyna* .	C4 plant, common at sea level to 800m. Occurs in cultivated fields, waste places, roadsides, lawns, and gardens. Found in perennial crops and pastures.
Asteraceae *Eclipta* sp. (GBSN)	53 genera 1 spp. *E. alba*	Common in pastures, and roadsides. Found all over Orissa. Is a medical plant. Occurs in poorly drained wet areas and can survive in saline conditions.
Tridex sp. (GBSN)	1 spp. *T. procumbens*	Abundant in pastures, banks, and waste grounds. In all districts of Orissa. Drier areas.
Cyperaceae *Cyperus* sp. (GPR)	16 genera 31 spp.	Plants of wet or marshy habitats. 7 species are very common rice weeds. All are found in wet habitats. Some in sandy areas.
Euphorbiaceae *Euphorbia* sp.	42 genera 21 spp.	3 spp common weeds, most found in rocky or sandy places, one spp prefers wet conditions.
Phyllanthus sp.	8 spp.	Most wet loving species and some occur just in the rainy period.
Gramineae *Cenchrus* sp.	90 genera 3 spp	Common as a plant of pastures.
Eragrostis sp.	16 spp	Some prefer dry conditions and others wet ground.
Ischaemum rugosum		Common weed of rice fields, found throughout India. Annual.
Malvaceae	13 genera	Includes common weeds such as many of the Sida species.
Polygonaceae	4 genera	Most are wet loving species.
Portulaceae *Portulaca* sp.	1 genera 3 spp.	Common in open places and all used as pot-herbs.
Rubiaceae *Oldenlandia* sp.	32 genera 13 spp.	Two species are common weeds of wet environments. Most are found in open, wastelands. Some prefer sandy soils.
Scrophulariaceae *Lindernia* sp.	25 genera 3 spp.	Found in swamps, and streams.
Scropia sp.	1 spp. *S. dulcis*	Common on waste ground and damper areas.

Figure 7.83 continued: Tables of weeds present in the archaeobotanical assemblages and their environmental implications.

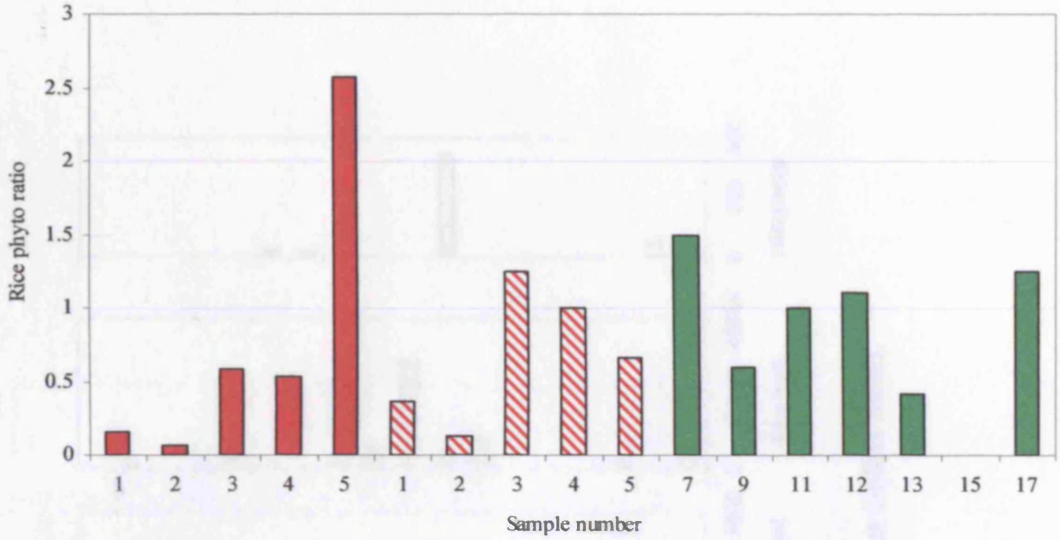


Figure 7.84: Graph showing the ratio of rice leaf/stem phytoliths to rice husk phytoliths at Koldihwa (plain red = Z1 and striped red = Y1) and Mahagara (Green).

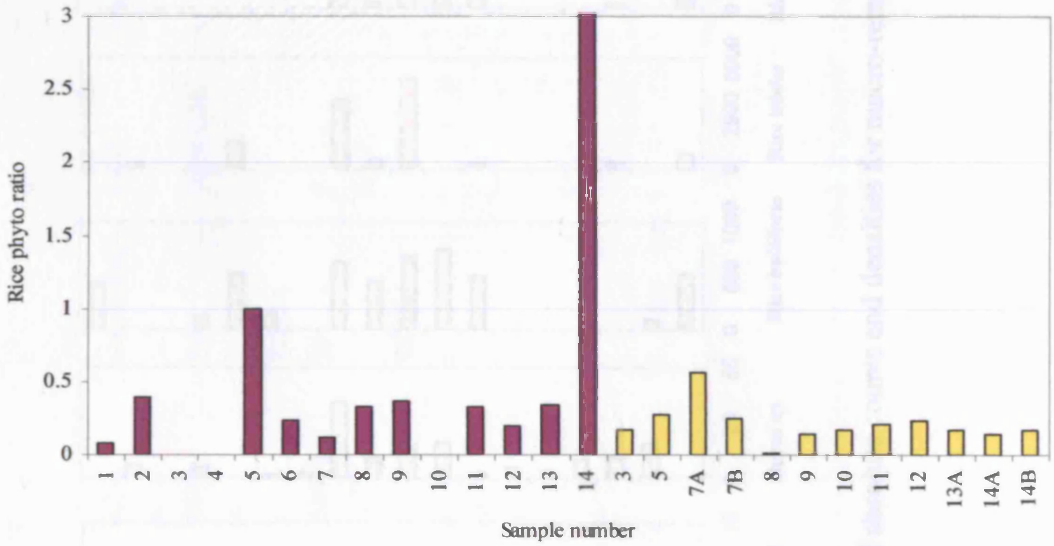


Figure 7.85: Graph showing the ratio of rice leaf/stem phytoliths to rice husk phytoliths at Gopalpur (purple) and Golbai Sasan (yellow).

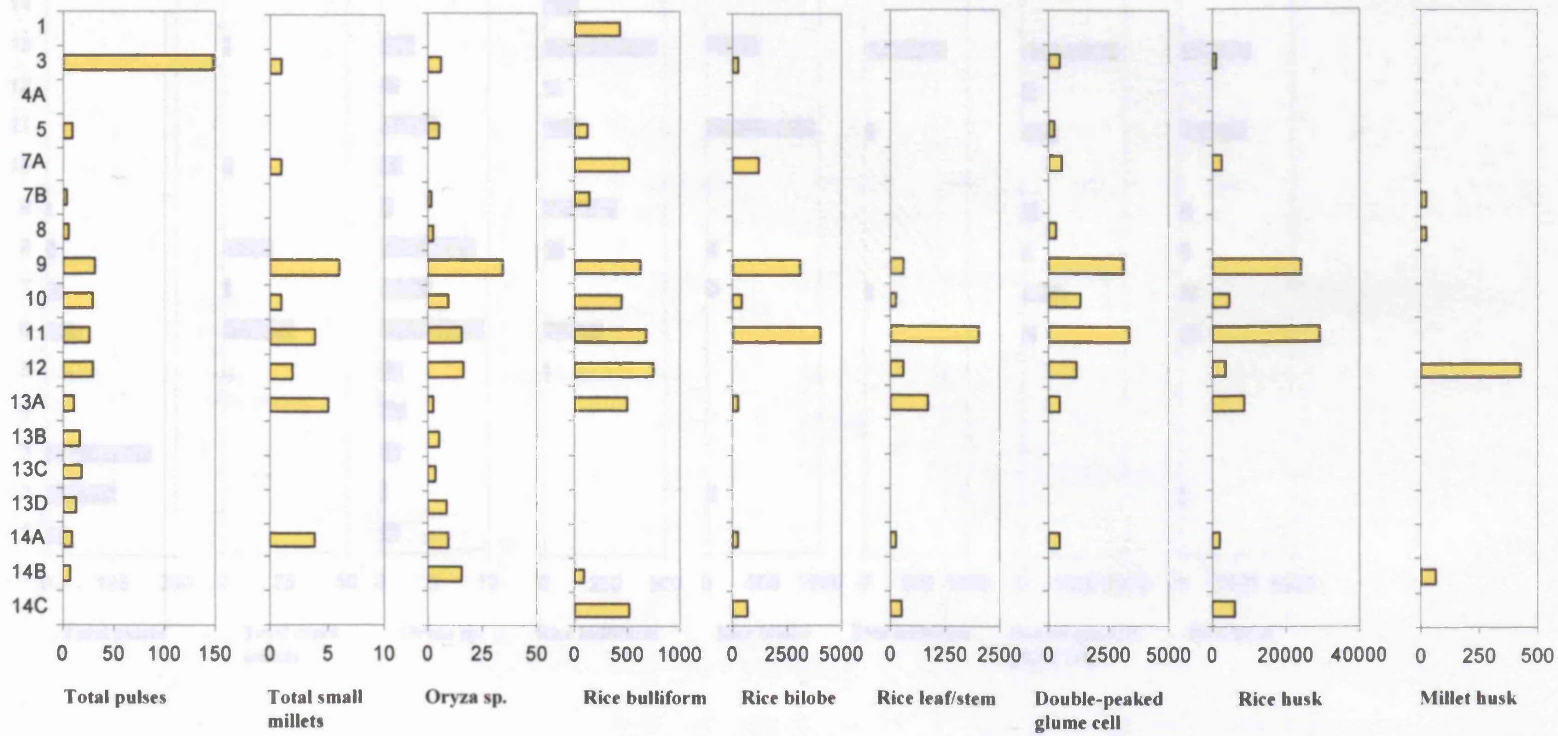


Figure 7.86: Vertical charts of absolute counts and densities for macro-remains and phytoliths at Golbai Sasan.

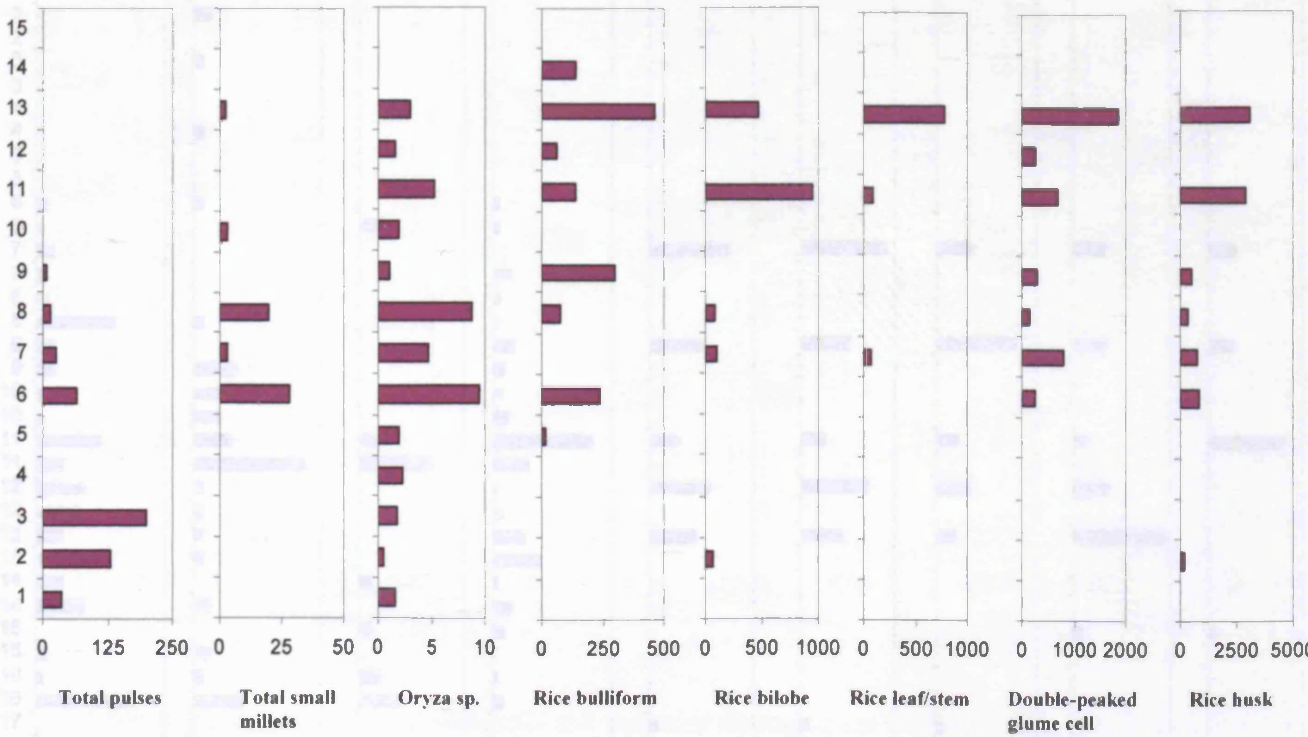


Figure 7.87: Vertical charts of absolute counts and densities for macro-remains and phytoliths for Gopalpur.

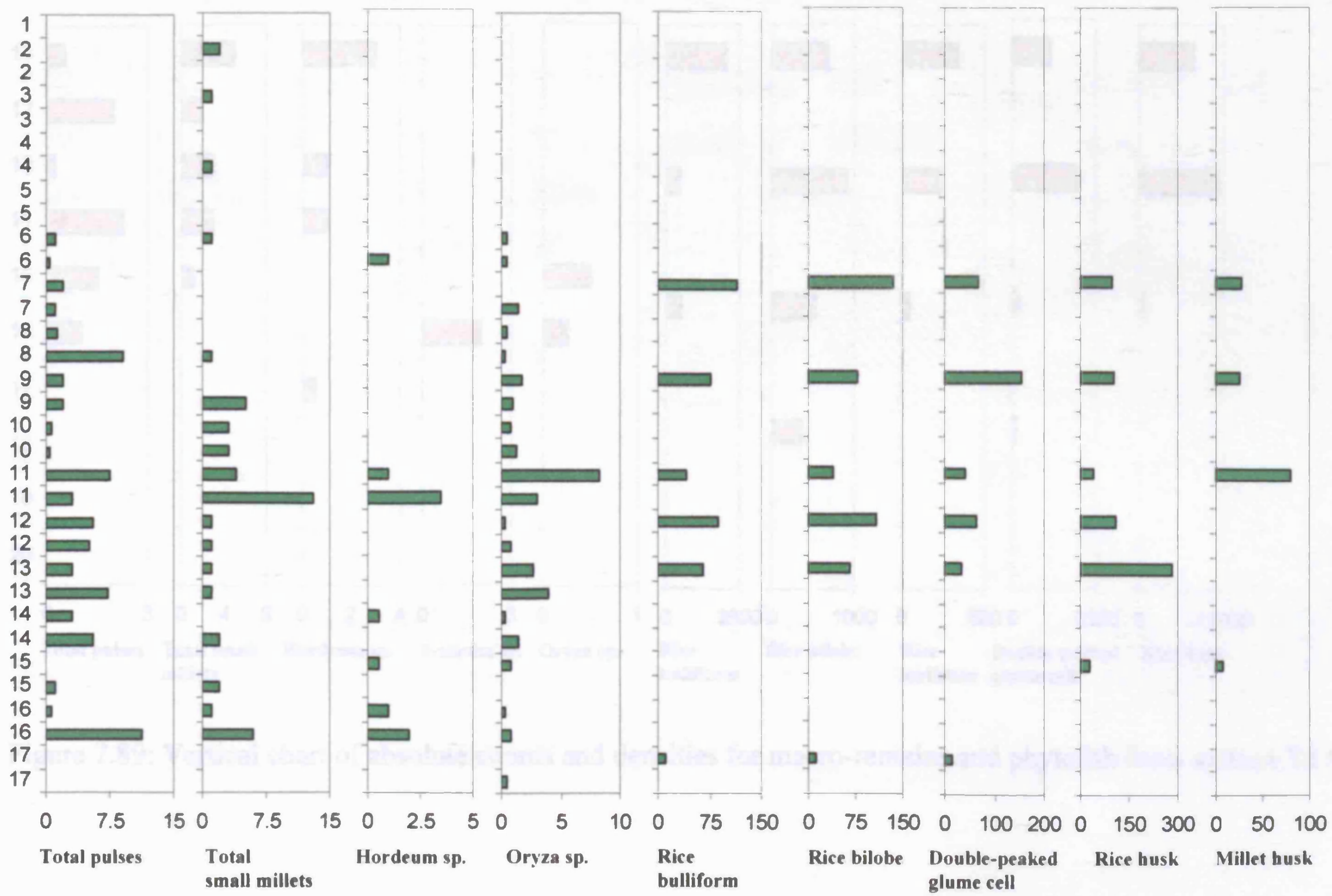


Figure 7.88: Vertical chart of absolute counts and densities of macro-remains and phytoliths from Mahagara.

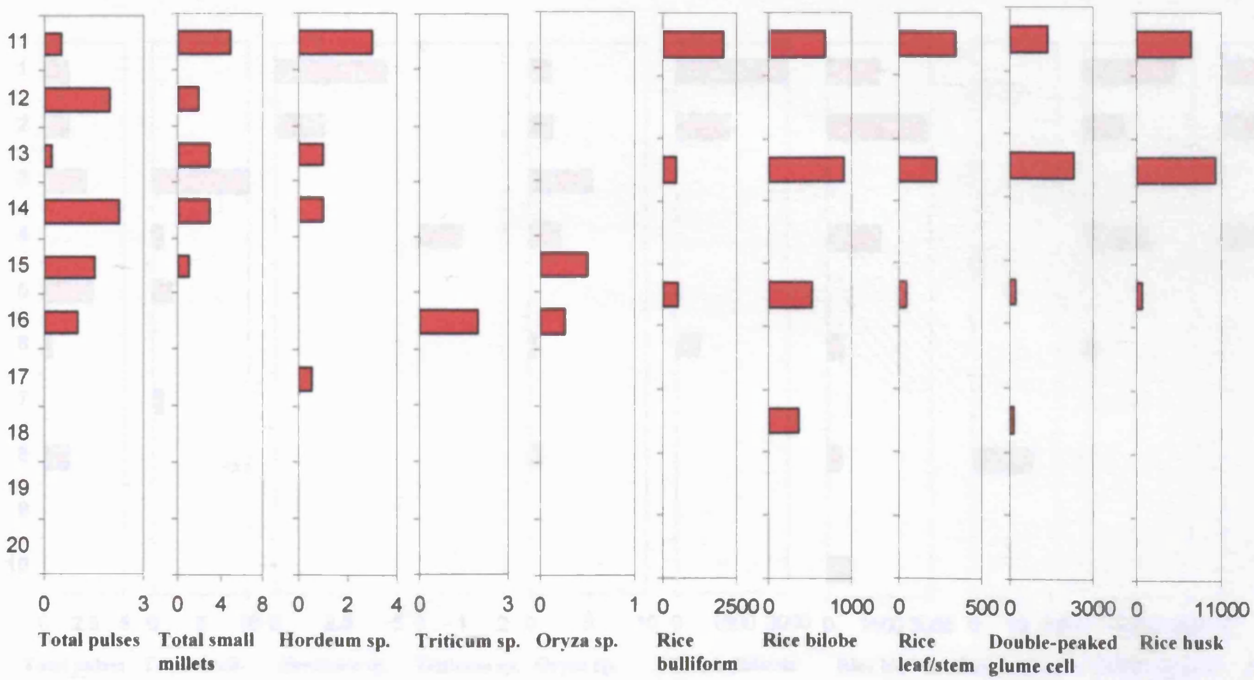


Figure 7.89: Vertical chart of absolute counts and densities for macro-remains and phytolith from section Y1 at Koldihwa.

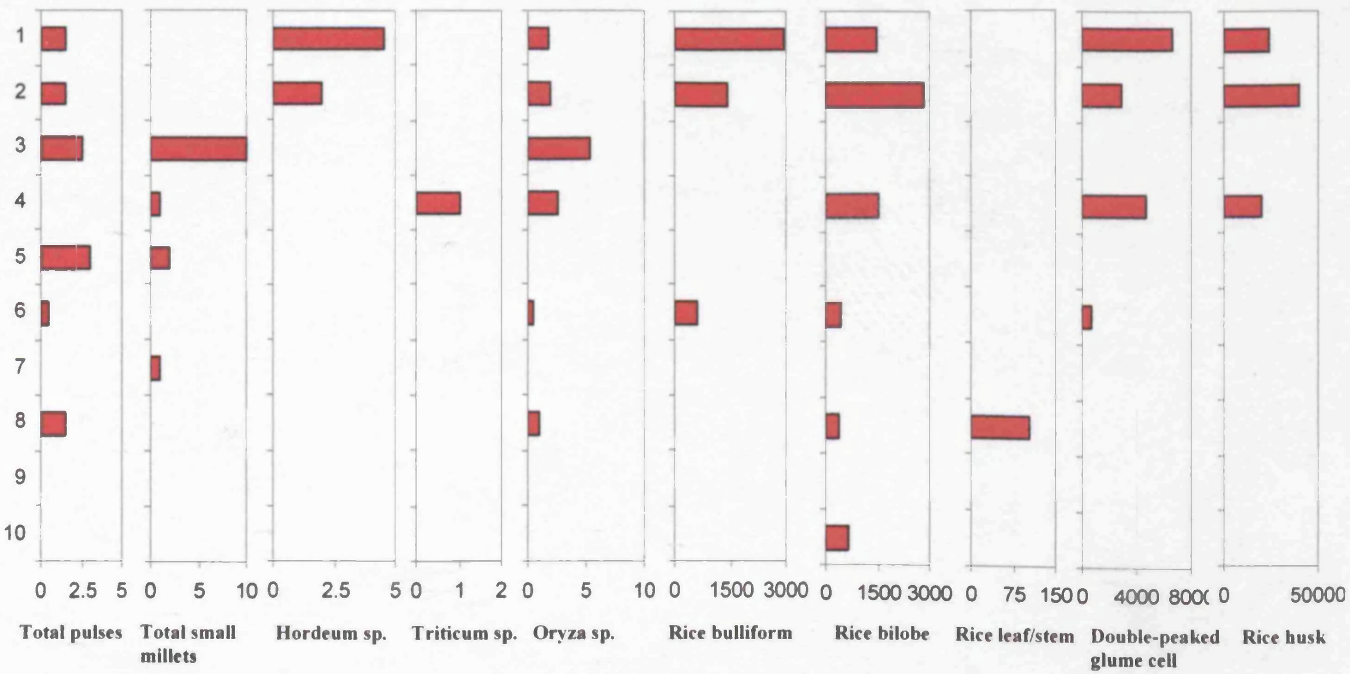


Figure 7.90: Vertical chart of absolute counts and densities for macro-remains and phytoliths from section Z1 at Koldihwa.